Teaching PHYSICS for the Inquiring Mind

BY ERIC M. ROGERS

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FOREWORD

This booklet is offered as an informal commentary on physics teaching in general and the teaching of science to non-scientists in particular.

In the later sections of this booklet "Physics for the Inquiring Mind" is used for examples (and details of teaching a course with it are given). Page references throughout this booklet refer to pages in "Physics for the Inquiring Mind."

Readers concerned with teaching an actual course with "Physics for the Inquiring Mind" will find some guidance in the sections of this booklet. Certain questions arise frequently: here are some short answers to immediate questions.

DOES THE BOOK COVER ALL THE TOPICS OF ELEMENTARY PHYSICS?

No; it covers a selection of topics put together to show their interrelations, and it contains a large enough sampling of the full field to do justice to physics.

THEN WHY IS THE BOOK SO BIG?

Because it aims at giving a good understanding of physics rather than a survey of methods or results; so it has to contain detailed explanations, alternative explanations, and much discussion of meaning and methods.

SHOULD ONE COVER ALL THE TOPICS IN THE BOOK IN A YEARS'S COURSE?

No. Our own course omits some. (See Preface to book.)

ARE LECTURERS AND CLASS INSTRUCTORS EXPECTED TO COVER ALL THE THINGS IN A CHAPTER?

No. This book is intended for a university course in which we say to students, "*We* discuss some of the arguments, and show some of the experiments; and *you* read the whole chapter."

HOW CAN THERE BE ENOUGH CLASS TIME TO WORK THROUGH THE IMPORTANT PROBLEMS?

There is not. The problems are meant to enable students to learn by doing them by themselves. To students: "*We* ask the questions; *you* learn by answering them. That is how adults learn."

WHERE IS THE ANSWER BOOK?

There is none. An instructor teaching a class needs to work through the assigned problems himself before he can comment helpfully on students' assignments. An answer book would tempt both Instructors and Students to short-circuit the careful working of these problems which are intended to provide essential teaching.

HOW CAN WE FIND THE TIME TO READ STUDENTS' ASSIGNMENTS?

There is no comfortable answer. The reading of students' work on assigned problems does demand time. But, since the problems here are a primary part of students' learning, reading their answers is a primary part of our teaching duty. Try using the problems and you will find them worth while.

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SECTION (I). INTRODUCTION

Teaching Physics for the Future

This is a discussion of physics teaching in college, for future scientists and for non-scientists. It deals with aims, methods and techniques for the teaching that is needed to promote better science and better understanding of science. It shows why a "block-and-gap"type of course both in general structure and in laboratory work seems best for non-scientists – and, in some ways, for future scientists too. And it describes the construction and running of such a course.

General admonitions are of little help without practical examples. So I shall draw examples from my own course and my own book that is used in it. I hope readers will forgive me for using my own material extensively, but that is the only way in which I can give working examples from a course that I know – a course that has been running for a dozen years.

And yet much of this commentary applies to physics teaching in general, and readers who want to reconsider their own teaching – in orthodox courses or unorthodox – will find both groundwork and examples for a general discussion here.

Physics Courses for Physicists and (some) Other Scientists

We hear talk of great needs in physics: new physics-teaching to train better physicists and more of them; better physics-teaching in school, in college, in graduate school, in training colleges for more teachers.

At advanced levels the prescription is obvious: encourage skillful young physicists to learn fast, by providing facilities, scholarships, and adequate teaching – adequate, because the really good growing physicist needs to teach himself, and gains more by contact with good research men than from trained teachers who make things easy.

At the freshman-sophomore level, (and earlier still when first choices of careers are made), skillful teaching is of great value; and the view of science that students form there is even more important. For that, some change is needed from the traditional elementary presentation of physics. The traditional course is thorough, well organized with rules, formulas, piles of information and routine numerical problems; and too crowded and too fast to meet our aims. Some paring-down of the content will leave time for more careful discussion, for arguing our way through physics as we hear it argued in laboratory corridors, for showing science as a connected scheme of knowledge and thought: in short, time to give the young scientist an understanding of physics before he chooses his career. Such a change is already being tried in some high schools (e.g. in P. S. S. C. courses), with chosen samples of physics well taught and discussed with enthusiasm. In college, most physics courses for future physicists, engineers, chemists, et al, have made only small changes in many years, except to hurry faster through electricity to get in a little more time on atoms. (To see how little, count the pages in standard texts!)

Many colleges, however, have embarked on quite new courses for non-scientists, where they require or offer a science elective. Some, in trying such new courses, have considered them so profitable that they are now offering much the same to pre-medicals – following requests by enlightened Medical School deans for better education in understanding physics. Therefore, while the course I shall use as my example throughout is a "new" course originally intended for non-scientists, much of its techniques and structure – and even its reason for being – point towards changes that might benefit traditional courses and help them to produce better young physicists and more of them.

The next section discusses the "new" courses and their aims in some detail. Readers interested in improving courses for future scientists will find some of their needs and problems discussed there too.

Physics Courses for "Non-scientists": The Need for New Courses

Much of the welfare of civilization, and perhaps even its fate, depends on science. Do our science courses educate students to understand this dependence? Scientists have a characteristic way of thinking and planning and working, which we call the scientific attitude or scientific method or science itself, that offers intellectual resources and guidance to all students. Do our science courses send their students out delighted with that understanding of science and ready to turn it in new directions? Can governors and administrators who have taken our science courses confer intelligently with professional scientists on the vital problems of our age? In general, does our science teaching make its proper contribution to liberal education? Even in the matter of teaching scientific information, are we meeting students' needs and hopes?

Young people are thrilled with the idea of scientific experiments and knowledge. Many a small boy is eager to learn physics and chemistry. When we show him a plain test tube, his tongue hangs out with enthusiasm. He longs to play with the first magnet he sees. Yet a few years of science courses – including, say some qualitative analysis or a study of magnetic-field formulas – will deaden the enthusiasm in almost all students. A few emerge still determined to be scientists – but even they usually have a strange picture of science as a sort of stamp-collection of facts, or else a game of getting the right answer. For the majority, well-meant teaching has built a wall around science, a stupid antagonistic wall of ignorance and prejudice.

In liberal education, we need not start the training of professional scientists (that can be done much faster once the vocation is chosen); we need not try to equip everyone with a lot of scientific information (that can be stored in books or left to the professionals); but we do need to give an understanding of science and its contributions to the physical, intellectual and spiritual aspects of our lives.

Suppose we think of our own children in college, majoring in economics or languages or history, but taking some science courses as part of their general education. With what questions should we test the success of such courses? We should hardly be content to ask: "How many facts have they learned?" Facts are forgotten all too soon. We are more likely to ask; "Can they think scientifically? Do they understand what science is about and how scientists go about their work? Have they a good feeling toward science and scientists? Are they likely to read scientific books in later life with enjoyment and understanding? Could they work with scientific advisers in business or government? Could they enjoy intellectual discussions with scientists?"

In asking such questions as parents and educators, we betray some of our educational aims. We should not agree on all our aims, but I think most of us have in common a number of aims and hopes which form a cogent group, demanding quite a different kind of science course from the standard ones now given in many colleges.

In fact, for many non-scientists, standard science courses are disappointing failures. Where we offer thorough training, we produce uncomprehending headaches. Where we give a comprehensive survey, we produce a muddled haze of facts and a misconception of scientific work.

A dozen years ago a number of colleges and universities discussed aims and plans and embarked on entirely new science courses for the non-scientist – courses in "General Education" in science. In this way they were joining a few brave institutions who had pioneered in such courses for many years. The "Harvard Report on General Education" did much to encourage the starting of such courses.

In parallel discussions at Princeton, I found we had to deal with practical details as well as general aims, and above all the reactions between aims and details. In comparing plans and schemes far and wide I soon found that while it was easy to secure agreement on general aims there was great disagreement over detailed aims of science courses for non-scientists, and over methods of achieving these aims. But then the picture began to take shape in an encouraging way: I found we could all start in agreement on general aims and we could all end in agreement on an important general prescription: the new courses should treat less content and pay more attention to good understanding and discussion of the nature of science. This "block-and-gap" prescription will be discussed in Section (II).

The New Courses and the AAPT Report

Such block-and-gap courses were tried in a variety of forms in a number of institutions. Many regarded them as queer, too unorthodox; and some critics hung ready complaints on them: "undisciplined," "too easy" ... complaints that were largely baseless. Now, as public concern over science-teaching grows, it is refreshing to find physics departments and physics teachers far and wide being urged by the American Association of Physics Teachers to study their Report of the Carleton Conference (1956) "On Improving the Quality and Effectiveness of Introductory Physics Courses." That report discusses objective and methods for all elementary physics courses, and recommends, inter alia:

> Physics teachers should devote more thought to the establishment of specific goals for introductory courses.
>
> Depth and understanding should not be sacrificed by attempts to cover too many topics in encyclopaedic fashion.
>
> Whatever content is selected, it should
>
> (a) Consist of sufficiently few topics so that each can be treated with thoroughness and intellectual rigor.
> (b) Present both classical and modern physics as growing subjects having present-day frontiers in all areas,...
> (c) Contribute to an understanding and appreciation of the logical elegance and unity of physics.
>
> As a minimum content, every course in introductory physics should include all of the following principles and concepts, and necessary material leading up to them:
>
> (a) Conservation of energy and mass (b) Conservation of momentum
> (c) Conservation of charge (d) The structure of the atom
> (e) The molecular structure of matter (f) Waves (g) Fields
>
> (The Report adds that enrichment would be provided by such topics as Electromagnetic Theory of Radiation, The Second Principle of Thermodynamics, Special Theory of Relativity, Quantum Theory.)

My block-and-gap course meets these admonitions closely in spirit and almost exactly in the letter of its syllabus; so I feel justified in using it as a specimen to show one way of implementing these important recommendations.

SECTION (II). AIMS AND TYPES OF COURSES

In all teaching, what we teach and how we teach are controlled, consciously or unconsciously, by our aims; by the outcome we expect. Before we can profitably criticise present physics courses or construct new ones, we must know what our aims are: and we had better examine those aims for feasibility. Before doing that here, take a look at the claims of our present standard physics courses.

The Case for (and against) Orthodox Courses

The standard, or traditional, course — easily named, but really a variable character hard to describe — is good at the beginning of professional scientific training; but in this discussion it is one of the villains of the piece. For many years, colleges all over the world have offered formal first-year science courses to their students — to science specialists and others alike. In most cases, these have grown to be courses in a single science with almost standardized content.* Emphasis tends to be on content rather than on ideas or scientific method or even thorough understanding; and the courses are intended to provide a sound foundation for more specialized work in their science. Many non-scientists take such courses, under rules enforcing "broad general programs" or through their own interests and choice. Such courses have been defended for general education on grounds such as the following (to which I have added a parenthetical chorus of criticism):

1. A good thorough grounding in science does show the nature of science. (However genuine this aim, I doubt whether real students find that orthodox courses do this for them. The topics seem to be crowded and unfinished. The teacher seldom has time to point the moral.)
2. Acquaintance with the main facts of a science itself is a valuable part of education for civilized life. (Facts are soon forgotten or muddled, particularly when delivered with authority and speed. If "education is what is left after what you learn has been forgotten," the providing of fact-content should not be the sole aim in science-courses for general education.)
3. The discipline of thorough study, including learning material that is boring or difficult, is valuable in itself. (Under criticism from phychologists, this kind of argument has lost favor in the field of classics. In science, it is likely to lose favor for the same reason. Also, it is likely to be crowded out by other aims.)
4. Study of science gives training in scientific method — that is, it makes people more scientific, a virtue to be transferred to other studies and other activities in general life. (This gives a cogent reason for any studies which do provide such benefits. Investigations show that such "transfer of training" does not occur easily or in great measure. To encourage it, we need to modify our teaching, as we shall see later.)

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* For example, nearly all physics texts intended for first-year college courses have almost identical content and much the same order of topics as each other. Each author seems afraid to omit what his rivals include.

5. A taste of science in a first college course gives some students a chance to decide they will be scientists. (This is true; but it may not be necessary to offer the samples in the traditional form.)

Many Aims for New Science Courses

A full discussion of aims would be endless, leading to unresolvable differences of opinion, tangled with educational difficulties rooted in differences of educational, social and political ideology. Committees have arrived at statements of aims, but the resulting lists are usually too impractical and too long. Yet there are common elements among the aims that different people propose and many of us have agreed in extracting a general prescription from them. Figure 1 shows a summary ranging from basic needs to general solutions.

Let us pay little attention to grandiose aims that are beyond the scope of real physics courses with flesh-and-blood teacher and students – aims such as fostering emotional balance or producing great thinkers. And let us pigeonhole aims that seem to us physicists side-issues, e.g., promoting good spelling. The more realistic aims on the table fall into three groups, dealing with content, training and understanding.

How far should we continue to give precedence to content, to coverage of subject matter? Imparting knowledge is common to all science courses, with aims ranging from making healthier citizens to training better soldiers for mechanized warfare. We rely on special courses to give specialized training; but, in general education, while some acquaintance with fact comes anyway, rigorous courses in facts and principles are disappointing. Perhaps we can neglect some of the fact-material now taught; then the rest of it may profit from more careful teaching, so that the student actually remembers more material, not less, some time after the course. Students who have a good understanding of the nature of science should be able to look up facts in books, and are likely to retain a lifelong interest in scientific reading.

So we have come to think that the more important things to aim at in science courses in general education are such things as understanding what science is about and knowing how scientists go about their work, rather than material knowledge alone. To give such understanding, we must modify the traditional courses, paying quite a price, in terms of technical training, for the gain we hope to make. So we ask, what are the values to be sought, and how can we construct a course that is likely to yield them? When we try to answer these questions, the problem of "transfer" appears again and again; so I shall discuss that problem before suggesting a list of aims.

The Problem of "Transfer of Training"

"Will students transfer training, in some skill or habit or the use of some idea, from a science course to other studies or to life in general?" This is a vital question. If the answer is "no," our new schemes must relate merely to better training inside a science, and offer little promise as a part of general education. If the answer is "yes," our hopes should be grand indeed. In earlier generations, courses in classics, history, mathematics, as well as science – in fact most of higher education – claimed cultural values on the ground that their teaching would transfer to many other fields of the student's education and there be retained as part of his mental equipment. Educators pointed to the high levels of scholarship and culture "produced" by a thorough classical education. In this they seem to have risked some confusion between post hoc and propter hoc – we might suggest their classical scholars had the intellect and background to succeed anyway. There have been growing doubts about this hoped-for transfer.

Since early this century, experimental investigations at first said "no" to our question about transfer, then later studies showed that it can occur to some extent. It

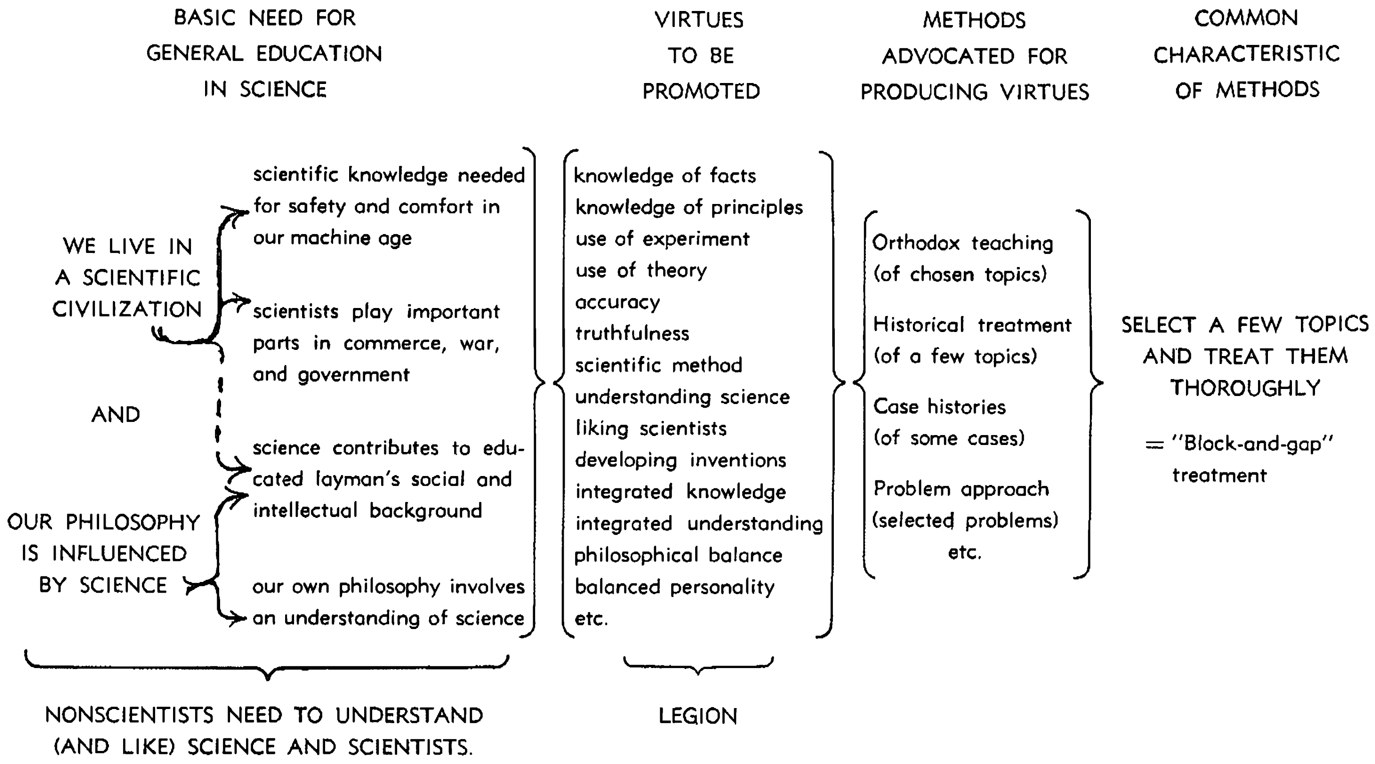
BASIC NEED FOR GENERAL EDUCATION IN SCIENCE
VIRTUES TO BE PROMOTED
METHODS ADVOCATED FOR PRODUCING VIRTUES
COMMON CHARACTERISTIC OF METHODS
WE LIVE IN A SCIENTIFIC CIVILIZATION
scientific knowledge needed for safety and comfort in our machine age
scientists play important parts in commerce, war, and government
AND
OUR PHILOSOPHY IS INFLUENCED BY SCIENCE
science contributes to educated layman's social and intellectual background
our own philosophy involves an understanding of science
NONSCIENTISTS NEED TO UNDERSTAND (AND LIKE) SCIENCE AND SCIENTISTS.
knowledge of facts
knowledge of principles
use of experiment
use of theory
accuracy
truthfulness
scientific method
understanding science
liking scientists
developing inventions
integrated knowledge
integrated understanding
philosophical balance
balanced personality
etc.
LEGION
Orthodox teaching (of chosen topics)
Historical treatment (of a few topics)
Case histories (of some cases)
Problem approach (selected problems)
etc.
SELECT A FEW TOPICS AND TREAT THEM THOROUGHLY
= "Block-and-gap" treatment

Figure 1. (From "Accent on Teaching," by kind permission of Harper & Brothers)

certainly does not take place as easily as educators and the general public hoped. If it did not occur at all, higher education would seem almost worthless except for special professional training. Fortunately there is some transfer — language teaching can improve intellectual skills, mathematics can give a sense of form or give training in careful argument, and so on — but only in certain favorable circumstances. In our present discussion, it is essential to know what these favorable circumstances are and to try to provide them We ask the psychologists who have experimented on this. Here is the essence of their reply;

1. Transfer is easy, likely to occur, when there is common ground between the field of training and the field to which we wish it to transfer; or when there is similarity between the influencing and influenced functions. For example, if we train a student to weigh accurately in a physics laboratory, it is almost certain that this training will transfer to another physics laboratory and he will weigh the more accurately there: it is moderately certain that he will carry his good training to a chemistry laboratory; but much less likely that he will carry it to any weighing in his own kitchen or in his business; and it is very unlikely that training in accuracy will reappear as a habit of being accurate in other activities. Another example: training in argument learned in geometry is likely to be transferred to later geometrical studies and perhaps to algebra, not very likely to be transferred to work in physics, unlikely to help the student to think

critically about arguments in newspaper advertisements, and very unlikely to make him a better economist. This is what the earliest experiments showed. This is what threatened to make liberal education seem hopeless: a study of Latin would not improve the general use of language,[*] mathematics would not sharpen the wits, science would not make its students more scientific – only technical education, direct training for use in a job, would bear fruit. In support of this disastrous conclusion, investigators pointed at the professional scientists, whose training should have made them tidy and systematic in all their general life and well-organized, logical, critical and unbiased in all their general thinking – in fact they range as widely from a common average as those in other academic groups. Happily for liberal education, later and more careful experiments showed that there is sometimes more extensive transfer: our intuitive judgment is right when we believe higher education makes some lasting contributions that spread outside immediate or technical training. But, only sometimes... only some contributions. Such generalized transfer is far more rare, far harder to achieve, than students and teachers hope and claim. In fact it is likely to occur only in special circumstances. Those circumstances, on which the hopes of liberal education should now rest, are outlined in 2 and 3.

2. Far-reaching transfer occurs when the common element is one of aim or ideal. Then the essential vehicle is the emotional attachment (or "sentiment") the student develops – the extent to which he associates feelings of enjoyment, interest, inspiration with his studies. The more he enjoys his science and is inspired by its skills and methods, the more he likes discussing its philosophy, the more likely he is to retain and generalize the teaching. Thus, reverting to our examples, a student who develops a delight in accurate weighing, making accuracy almost a minor ideal, may well carry the techniques and attitude of seeking accuracy far and wide in his activities – particularly if he has been made aware of the possibility and value of this wide transfer. The student who gains skill in geometrical argument and develops an ambition to use the method may well become the clearer lawyer or cleverer economist by the transfer of some of that training.

3. Conscious efforts toward transfer can help. We can make transfer more likely by making a student aware of his gains in one field and pointing out their applicability to other fields. That is why I visit each laboratory section of my course early in the year, and talk about hopes of transfer. And I have included that talk in Chapter 4. (Please read pages 62-63.)

4. It has been suggested that ease and amount of transfer increase with increasing general intelligence. This seems reasonable in the light of the other requirements. If this is true, the brightest students should profit most from courses in general education.

Discussion of Some Important Aims

With the difficulties of transfer in mind, we can now review some of the benefits aimed at or claimed in science courses. We can see that a standard course full of information, enlivened by demonstrations and exhortation, may fail to make any great contribution to general education, and may even fail to educate students in science. In planning new science courses we find a variety of aims suggested. I shall list some of these with comments.

1. Teaching Scientific Method(s). The course should "teach scientific method," that is, show how scientists attack a problem: gathering data, sorting data, making and testing hypotheses, suggesting and trying further experiments, until theory and experimental knowledge are built into the structure of a science.

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[*] Experiments with parallel, matched groups of university students showed Latin producing little effect outside its own field.

I think there are two kinds of aim here: (a) training in scientific investigation, both in science and outside and (b) showing the student what science is like. The former training would be a fine part of a student's education if we could really equip him to use it, but it is doubtful whether we can train people to behave much more scientifically in their general life. Also, the scientific method — if there is just one, and I doubt this — may not be so wisely applicable to other studies such as the social sciences. Perhaps the most we can hope to do is to encourage a scientific attitude and critical thinking in general life.

In aim (b), showing what science is like, we can go much farther. Traditional courses try to do this by imparting knowledge of facts thoroughly; but not only do they tend to crowd out the teaching of method and the showing of the nature of science, they also make students form a mistaken picture of science itself as a body of fact provided mysteriously or drawn from sources known to only a few. However, science courses can be made to show the methods and growth and nature of science, perhaps by historical treatment, perhaps by other methods. But in all cases there must be time for students and teachers to discuss these matters, which should be presented with active attention to their part in the student's education. In a way, the patient needs to be reminded that he is taking good medicine and that if he cooperates he may expect great benefits.

In the teaching of scientific methods we find "encouraging critical thinking" as one of the aims. Here we may hope for some transfer, but only if we plan for it. We may use the course as ground in which to grow habits of critical thinking. Scientific work involves great care to avoid bias, so it is easy for the student to see the need for logical, unbiased thinking in science. However, we should not assume that mere contact with science which is so critical will make the student think critically. I think this is an important aim, not easy to achieve — often not achieved in the measure its sponsors claim or hope — to be sought by giving students time to discuss scientific material critically and creatively. Humanists would claim that their fields provide good opportunity too — for example, courses in logic, philosophy, poetry, history. However, like the scientists, they have spoiled their chances by choking their courses with too much material and some have soured the customers by their preoccupation, in examinations, with the "detestable testtables" such as spelling and dates. Scientists feel that their field provides easy, clear-cut material for this teaching.

2. Giving Creative Work. There is a tendency in modern fact-jammed education to starve students of creative activity. Many a graduate in science emerges with no memory of creative experience in college. Yet without such experience, civilized man is a dull fellow and college has little chance to make him better. Students can do creative work in science if they are given time, opportunity, and encouragement instead of being told, "That was known twenty years ago," or being instructed, "Do this problem properly, the way the book tells you." Laboratory work can provide a sense of real creative work for some. Reading, with some free choice, can give it to others. For others, essays and discussions can provide it, but these should deal with thought-provoking questions rather than routine problems. With our interest turned toward it, we can promote creative activity.

3. Cultivating General Abilities and Training the Mind. This sounds like an educational catch-all, but it is an expression of our general hopes for "transfer" from science. These are the aims I consider unrealistic, for which there is neither much hope of transfer nor much opportunity for direct treatment in a science course. Yet most course-planners mention some such aims. I suggest all teachers and planners should review these general aims before they start, then place them on a storage shelf, marked IMPRACTICAL where they may remain as laudable ideals.

4. Teaching Basic Principles. "Understanding of the basic principles of the

physical and biological world, their implications for human welfare and their influence on the development of thought and institutions" would seem, at first reading, to be just the kind of aim many of us have in mind. But can we make the student understand the basic principles? If so, will he be able to see their implications beyond science? There seems to be a hint here of a set of indispensable topics, the basic principles, making too weighty a list. A thorough study of basic principles might concentrate attention on subject matter to the exclusion of teaching of method and ideas. Many of us doubt if we can – or even should – teach the basic principles and their implications. A choice of a few basic principles might be wiser, giving time for other matters. The particular choice may not be very important, provided this restricted choice leaves time to study the development and interrelations of the chosen topics.

5. Showing What Science is Like, What Scientific Procedure is Like, and What Scientists are Like. These, I think, are the most real and probably the most important things we expect from a science course. Our courses should mediate between the scientist and the layman, between a classical culture and a scientific civilization. They cannot do this just by pouring in scientific information or even formal training. What is needed is a genuine understanding of science and the way scientific work is done. To make this understanding a lasting part of peoples' culture is a huge task. In a year's course we can give only glimpses of it.

If the student is to retain such valuable knowledge and ideas, we must give him opportunity and time to make them his own, not just have them thrown at him by a provident teacher. Some students will need to learn what scientific work is like by doing, by experimenting independently in the laboratory, and thinking about the meaning of their experiments. Others need not be restricted to this excellent but very slow way of learning; they can learn by studying the work of the great men of science, watching its growth in the framework of science, against the background of history. Others can learn from direct teaching of science – science as it now is, with some attention to the way it has grown to its present state. Class groups with many students probably need a mixture of these approaches.

Whatever examples of scientific work are chosen, they should be studied thoroughly so that students can see the way the work is done and appreciate the methods used, so that they do not merely learn the results (for examinations) but see how those results take their place in the framework we call science. In particular, they should see how theory and experiment are related in each example studied. Ideally they should see how both the work and the results are related to the social and intellectual life of the times when the work was done, and perhaps see how they affected the life of later generations. Such general understanding of science needs specific examples; but these cannot just be presented as glimpses. The student must understand the facts well, then think about their meaning and relationships. The teacher must help him to turn his attention in different directions, and must encourage him to generalize the understanding he is gaining. Thus, to give understanding, we must teach a lot of solid physics.

To understand WHAT SCIENCE IS LIKE is a big requirement. We have only to look at the popular misconceptions of science – in a civilized world where science has been taught to many for generations – to realize that these cannot be due to unsuitable teaching alone. To show WHAT SCIENTIFIC WORK IS LIKE is easier, because separate examples can build such an understanding and the student can see more easily what kind of thing he is learning. Perhaps easiest of all is to show WHAT SCIENTISTS ARE LIKE , not in their personal characters but as workers and thinkers. Students should see how some of the great scientists approached problems, how they worked, and what their results meant to them and other scientists. They can learn the ruthless truthfulness with which scientists try to base their work on experiment. They can see experiment and theory playing their complementary roles in the hands of real scientists. They can learn how theories (or conceptual schemes, or even just "ideas") are neither wild guesses nor true pictures, but wise imaginative complexes of ideas and knowledge which coordinate thinking and promote further knowledge.

If our non-scientist students can learn such things as these, they will form a new generation of laymen able to appreciate scientists and to work with scientist neighbors with delight and understanding.

Quantity and Arrangement of Subject Matter

Our discussion of aims suggests that while details of content are not very important, the quantity of content and the general structure of topics are matters of great importance in the new courses. Accomplishment of most of the aims requires time. There must be time for student discussion, for careful reading, for historical analysis, for arguments and expositions of the nature of science; above all, for the student to turn around and look back on the way he has traveled, trying to understand what it is all about, instead of merely knowing facts or rules soon to be forgotten. Some teachers claim that the history and nature of science are discussed in orthodox formal courses. But it seems certain that orthodox courses do not give sufficient time for this; and thus by their very crowding and attention to preparation for later courses, they give an erroneous picture of science. So, a general characteristic of the new science courses seems likely to be a great reduction of subject matter. Of course this reduction has no intrinsic virtue. It is merely the key that opens the door to teaching-schemes which do have special virtues.

Terminology. The Block-and-Gap Scheme

To make discussion easier, I offer the following descriptions and labels. (See Figure 2.) Let us represent the whole field of knowledge by a table of columns, as in (a), each column representing the subject-matter for a single science. For example, the column BCC'B' represents physics. The standard course proceeds straight down a column covering the subject matter as thoroughly as time and the students' preparation will permit, usually trying to lay a foundation for later courses. Some colleges have several standard physics courses for students with different preparation or intersets. These are sketched in (b) as alpha, beta, and gamma.

Alpha is a "thin" or easy course which begins at the beginning and does a thorough job of mentioning topics but avoids the hard parts of the treatment. In physics, such courses are often recommended for students who have not studied physics before, and they are sought by many premedical students. They seem hard enough to their clients, but to their instructors they often seem too easy and too dull. In tests, easy numerical problems are more common then derivations involving argument, and the student's real understanding is not inquired into.

Beta is a standard "freshman course." All the important topics are treated in turn, with little time to show consequences of interrelations. History is mentioned occasionally but not discussed and certainly not brought to life. The course is well packed with content. In physics courses of this kind, problem-solving still involves many arithmetical substitutions but contains some algebraic argument.

Gamma is a harder or more advanced course given in some colleges, for students with special preparation or interests. Note that since this course trades on students' previous preparation, it can omit considerable patches of material, while expanding others or even treating them as case-histories. Curiously enough, a gamma course is often a specially hard version of the block-and-gap course suggested for general education — there is

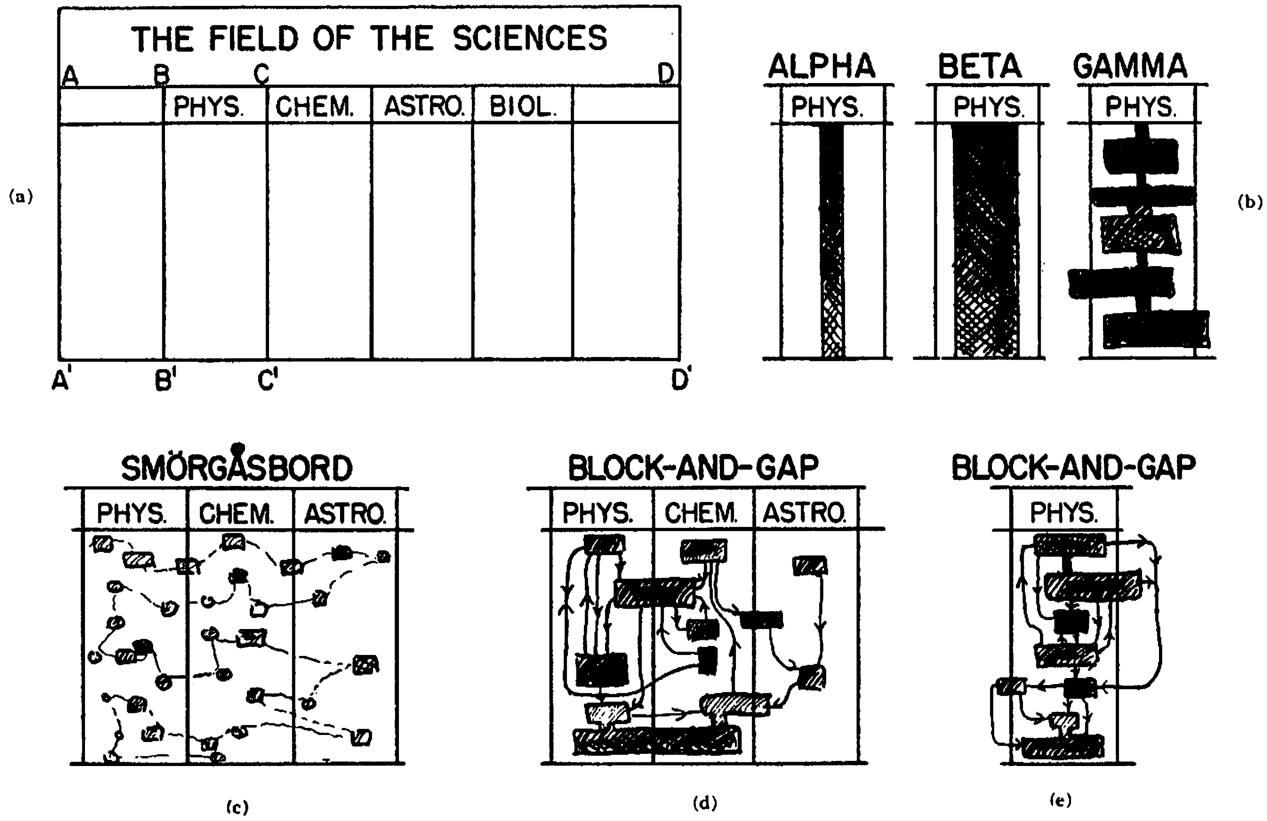

Figure 2. Quantity and arrangement of subject matter in college science courses:
(a) The field of scientific knowledge, divided into separate sciences;
(b) orthodox elementary physics courses;
(c) a "survey" course in physical science;
(d) a block-and-gap course in physical science;
(e) a block-and-gap course in physics.
(From American Journal of Physics, by kind permission of The Editor)

a useful moral in that for the future development of courses for physicists.

One type of course used for general education has been a "survey course" which at least mentions a large number of topics. Some claim that this gives valuable wide acquaintance; others condemn it as giving a smattering of facts with no time for either thorough treatment or discussion of ideas. We may sketch this in (c) by selecting some small patches all over the wide table of the sciences. If we like, we may draw a connecting thread linking the many topics in a pattern, but little blood is likely to flow along so thin an artery. I call this the "smörgåsbord" course. (The title "survey course" has several meanings and is best avoided.) As thus described – a wild rush through a host of little topics – this is not the course any of us wish to claim as our own, not even the proponents of several kinds of "survey". We each disclaim it, and perhaps think it is the course the other fellow gives! We feel the smörgåsbord course does too little to show the structure and methods of science. And, even at the college level, such a course tends to glorify the "wonders of science," paint the romance in glowing colors, and make the scientist seem a wizard who dispenses knowledge and "explanations." Science courses should debunk such pictures. There is romance enough – and the great delight of understanding – for students to find in the art and knowledge of real science.

A scheme better able to meet some of the requirements discussed runs more like the one marked "block-and-gap" shown in (d) and (e). This may be in a single science or in a mixture. Its essential characteristic is that large quantities of material are omitted outright, so that only some of the topics of an orthodox course such as beta are dealt with – say, half the topics. Those included are treated thoroughly as to subject matter (the blocks representing such topics are dense) and as to their background (the blocks extend out toward other topics and other sciences and are clearly related to other blocks). Connecting these blocks are lines along which flows the "lifeblood" of the course: discussions and investigations, historical studies, ideas and information carried from one block to another, and thence, enriched, on to still another or back to the first one – showing the organic structure of science. The gaps are essential; they give room for the lifeblood to show interrelationships, and they reduce the content of the course so that there is time for discussion, time for ideas to sink in, and time for the student to look back and reconsider. Whatever our differences of aim and course structure, this name "block-and-gap" with its crude picture seems useful as a description of the kind of course we are trying to provide for liberal education.

Though they indicate something about the course structure, these pictures say little about the type of approach or treatment of the material which is selected; nor does the block-and-gap picture say what material is selected. In block-and-gap, the approach may be historical (as it may be in beta), perhaps through case-history studies or through readings of original texts; or it may be empirical by experiment: or the course may be composed of selections from an orthodox course, with a change of attitude. Still, we are likely to agree on some general characteristics of the block-and-gap course: restriction of topics, attention to their interrelations, and prominence to student discussion and creative work.

Critics, seeing the name "block-and-gap" may complain that a set of unrelated topics lightly treated would make a poor course, a sort of emaciated survey. This is not what I intend the term to mean. The blocks are meant to be related, by pointing the moral from one to the other by referring back to earlier ones or prophesying forward to future ones; and their topics are meant to be treated seriously. To show what science is, we must ask students to learn real science thoroughly – there will be plenty of solid content. In fact, the blocks should be both dense and extensive. The discussions should be thorough, explaining essential points carefully, and they should extend to neighboring material, pursuing some of it to an advanced stage. For example: a traditional beta course in physics will certainly treat the kinetic theory of gases, probably stopping at a prediction of Boyle's Law and a brief mention of diffusion. In a block-and-gap course, kinetic theory may be selected as a block or it may be omitted; but, if it is selected, it is likely to be treated more slowly and thoroughly so that students have time to discuss its assumptions and to understand its mathematics (instead of memorizing the latter parrot-fashion for examinations), and to see its use as a theory. It is also likely to be treated more fully. If it is done at all, it is done well. Just saying, "There you have a prediction of Boyle's Law... Avogadro... diffusion...," then hurrying on to a new topic, may teach something about kinetic theory but it is likely to leave the student little the better in his understanding of science. He needs to have time to discuss the parts played by assumptions and the mathematical machine. And he needs to see more of the results that the theory can yield. If kinetic theory is studied in a block-and-gap course, it may well be continued through experiments to measure molecular speeds, comparison with velocity of sound, and a discussion of gas viscosity – with an experimental test of the theory's surprising prediction that gas friction should be independent of the pressure. Here is theory being used and tested, then made to predict and use the breakdown of its own prediction.

Making a Block-and-Gap Course

In offering a block-and-gap course as part of general education, we try to show, by means of picked specimens carefully treated, what science is like, how scientific work is done, and what scientists are like as thinkers and workers. In preparing such a course the first thing we have to do is to make it clear to all who teach in it that the gaps are big, that they are not expected to cover all the ground of a course like beta. Then we must assure them that there is no single, ideal collection of blocks. In Section (III) I shall describe the selection of blocks in my own course and how I constructed it. I recommend it only because I have found it works well, and I have written my book to fit it. But my advice to colleagues who plan to start such a course elsewhere is:

> "Think out your own aims and syllabus. Though yours and mine may differ, neither of us need be wrong: each scheme may fit the man giving the course. For non-scientists, I urge a block-and-gap treatment; but that does not settle the choice of topics or even the system of teaching. Choose between case histories, demonstration lectures and standard teaching, and historical treatment; and choose your own group of topics.* The process of thinking out your aims and planning your scheme will make your course fit you; and it will make you more fully aware of its structure and give it a vitality that is important for a course with such aims. Ask yourself and your colleagues, 'Why do we teach science to these students?' and, after the usual reply, 'What are scientific methods?' Then go ahead and teach with a happy heart, exercising three censorships:
>
> (1) Do not include a topic unless it either illustrates an important matter of philosophy or crops up in several places, showing important linkages.
> (2) Do not rush through laboratory experiments. Think what you are after.
> (3) Think carefully about problem-assignments and examination questions.
>
> Your selection of topics should amount to about half (or at most two-thirds) of the content of a traditional course. Make a selection which will have interconnections, showing some kind of a framework of science. Then you and your class can go ahead and think and argue and discuss and learn good science."

The Essential Requirement

Whatever scheme of structure and methods of treatment we choose, the essential requirement for any science course is that all its pieces should be linked together. The interrelations between topics are as important as the topics themselves — we need to point out those connections again and again. This requirement makes great demands on text-book, and problems and laboratory work. Ideally, the text should not break up into chapters that can be studied separately from each other. Ideally, the problems should involve many pieces of knowledge and reasoning, and not be limited to single topics. Ideally, laboratory work should be the student's own investigation of nature, not a well explained, clearly defined, exercise on the chapter of the week. When we find these learning aids falling far short of the ideal, we must put our trust in two strong human influences: the student's wish to learn science as a whole — a wish that can be suggested and encouraged — and the skill of every good teacher as an active guide towards connected knowledge.

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* To others who then suggest adding just a few more topics, you should say (as I do), "By all means add those, but for each one you add please cut out at least one of my topics."

SECTION (III). MAKING A BLOCK-AND-GAP COURSE

Choosing Topics

How should the blocks be picked for a good course? There is no golden rule. To a colleague starting such a course I would like to say,

> "This is your course. Make your own choice of blocks so that you have a strong sense of the interconnections between blocks. Do not crowd the course with too many blocks. Although you choose only a few topics, and although much of students' attention is concentrated on methods and ideas, they will learn enough facts (and learn them well) to seem well-educated in the old-fashioned sense. And they will enjoy learning and reading science for the rest of their lives."

Some teachers designing courses then decide that treatment is so much more important than syllabus that they are willing to try a ready-made block-and-gap syllabus, provided there is reading material to go with it. That is why I am now going to discuss my own material in detail. Nevertheless each of us has strong preferences and dislikes in course material; and it would be unwise to offer only my own minimum version. Therefore, my book makes excursions into other topics for those who prefer them. I hope that this will encourage selection and not an attempt at crowding.

Planning My Own Course

In planning my course I reviewed the main aims suggested by others. They fell into three groups, (as in Fig. 1, earlier):

Group 1. Content. We must impart scientific facts and principles.

Group 2. "Higher virtues" such as training in accuracy, critical thinking, scientific thinking, scientific honesty, balanced personality, and (of course) scientific method. (I am sure there is no unique scientific method.)

Group 3. Understanding and appreciation of science and scientists, of lasting value in later life. This involves a happy acquaintance with science, some knowledge of scientific material, some understanding of the methods of science.

I decided that Group 3 should be my paramount aim, that Group 2 is practically unobtainable, and that Group 1 has been overdone, with bad effects on the reputation of science. Content is useful, of course, in kitchen, factory, life in general; and I planned to teach a considerable body of facts and principles, but not so many as to make the course crowded, rushed, unfinished. Facts are soon forgotten. Ten years after college, what is left? Certainly not the facts; and even the principles are ill remembered. (Be realistic; ask your non-scientist friends.) So I proposed to reduce the content to about half that of a traditional physics course. (I find that others giving such courses agree with this reduction: about 50%. A cut of 10% would be mere paring, while a cut of 80% would reduce the course to pleasant storytelling.)

"Higher Virtues," as listed above, would indeed be wonderful. But science teaching cannot confer these benefits on pupils unless the training given in science classes can somehow be "transferred" to other fields of study and to life in general. Psychologists tell us that this is highly improbable unless the situations are similar or the motivations are strong. So I proposed to disregard the "higher virtues," or at least to shelve them as not directly attainable.

My Block-and-Gap Course

Here then, is the plan which I have carried out for several years, with some reassurance of success from discussions with students, examinations, and questionaires. I give a block-and-gap course in physics in which I try to make students understand – and like – some parts of physics, and then understand what science is like and what scientific work is like. These, I think, are the most real and probably the most important things I expect from my course.

Some of my teaching is given by lectures, with demonstration experiments to be argued about; some by small class sections, where good scientists discuss good science with students as fellow scientists; and some in laboratory, where experiments are informal and are given plenty of time, with few instructions.

This is a block-and-gap course taught by orthodox class methods. I do not believe there is magic virtue in any particular method of teaching. I might change to a block-and-gap course of case-histories, if I had a staff of physicists with expert knowledge of, and genuine enthusiasm for, the history of science.* As it happens, I have a staff with genuine enthusiasm for contemporary physics.

We first help the student to understand the facts well, then stimulate him to think about their meaning and relationships, and then encourage him to generalize the understanding he is gaining.

As a basic policy, I teach pieces of good physics, as samples of good science. If I can give a keen sense of what science is like in my course, then some students may be able to link science with history or religion, practice physical methods in sociology, or apply it to their personal lives. It is my duty to point out such avenues to my students and urge them to explore; but my main work must be good science, or I defeat my main object and with it all others. I will not prostitute my physics course to the exposition of scientific sociology or to exercises in English reading.**

I try to achieve my special aims (in contrast with just imparting knowledge):

(1) by raising philosophical questions in lecture – "There's Hooke's law. What do you mean by 'law'? Who obeys what?"

(2) by encouraging discussion and argument in class – "What makes an experiment a success? ... (silence) ... "Well, what makes a party a success?" ... (hubbub). "Now what makes an experiment a success? Let's make a list of different peoples' views."

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* I have doubts about historical approaches for the average non-scientist. When I read case-histories myself I am thrilled; I enjoy reading Boyle's difficulties and arguments and experiments, or linking Newton's work with the social, intellectual, and philosophical background of his time. But then I know some of the physics and chemistry of these matters already. Does it follow that this is the best fare for freshmen? I find some historical treatment is useful, almost essential; but as a major policy for teachers I leave it to the rare genius who has his heart in history. I fear the professional historian of science can never replace the professional scientist in teaching laymen to understand science. His interests and techniques are different; and perhaps without knowing it, he teaches commentary on science rather than science itself. To many a non-scientist Dean, history-of-science is a surprisingly tempting substitute – perhaps that Dean's error illustrates the present need.

** But semantic questions crop up often in my course, quite rightly. "Why is it uncomfortable to say an electron is a wave and a particle?" Even some definitions give much food for thought.

(3) by running laboratories slowly, with discussion-meetings after the experiments.

(4) by assigning weekly problems which raise discussions. These problems give important teaching. Since they are not examinations, we can ask vague argumentative questions that lead to useful talk.

Choosing My Scheme of Blocks

Here is how I chose my own blocks. I consider choice of blocks less important than the way they are treated. Yet my topics must hang together, one preparing for another, and one reflecting back to another; the whole framework must "make sense," like science itself. So when I had chosen a few blocks for special reasons the rest followed as necessary parts of the framework. For student interest, I decided to make "atomic physics" prominent, including the cyclotron (as a good example of an accelerator) and including nuclear physics (for its importance and interest). This large block, with all the ground work needed to make it seem sensible instead of magical, fills much of the year. It hangs together and offers good opportunities for matters I want to discuss.

I trust to laboratory to provide for some worthy minor aims: teaching household-electricity (volts, amps, watts, etc.); contrasting extrapolation with interpolation; showing how empirical experimenting leads to laws; showing how research is planned, and how the experimenter keeps an open eye for the unexpected; showing honesty in treating observations. As its major, over-all function, laboratory enables students to experience the delights and sorrows of experimenting.

Yet the relation of theory and experiment – a paramount matter for discussion – would still get a poor deal. Atomic theory is too profuse; much of it must be taught by the "handout" method, which spoils some elementary science teaching. Kinetic theory of gasses is too difficult for a beginning. So I spend some six weeks early in the course on an old friend, the history of planetary astronomy. Here is history in a welcome form, and here is a magnificent, easy study of the growth of science: from empirical knowledge to machinery and laws, and then, with a jump, to a grand deductive theory. I start with unreliable information about primitive man, run through Greek astronomy, build the Ptolemaic system, study the work of Copernicus, Tycho Brahe, Galileo, Kepler, and Newton. I give some account of these men's lives to make the scientific growth easier to learn; but my main preoccupation is with the changes in the nature of science.

Nuclear physics, cyclotron and planets, those three topics, together with the necessary ground work, write my syllabus!

Start with nuclear physics and the cyclotron and work backward, filling in the needs. To understand the working of a cyclotron, instead of just hearing tales, students must know how ions can be made, accelerated by electric fields, and tethered by magnetic fields. Students should try for themselves the "cyclotron algebra" for an ion moving around a circular orbit and find the essential result and, I hope, delight in its simplicity. That means they must know the force exerted by a magnetic field on a moving ion, and they must use $F = mv^2/R$. Therefore, they need an elementary knowledge of currents, charges, magnets and fields. They also need to understand and use, $a = v^2/R$;* and that leads back to Newton's laws and vectors. Meanwhile *uses* of a cyclotron involve radioactivity and nuclear physics and these require a knowledge of atoms and ions, leading back to simple chemistry and molecules and again to electric fields and mechanics. A good understanding of energy has already been needed again and again (e.g., in electric circuits, cyclotron, nuclear physics); so energy and energy-conservation must be discussed fully. Kinetic theory of gases offers a good beginning by tying together energy and molecules in a good example of theory. Again that leads back to a thorough discussion of Newton's Laws of Motion.

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* I would not use v^2/R without deriving it. I would not derive it just once and leave my class with a headache. I hesitate to spend time on a series of attacks if it is to be used just once. But it has many uses: essential in Newton's astronomy, in cyclotron ("no algebra, no cyclotron" is my motto; I am not running a kindergarten), and essential for a lab experiment in which students measure e/m for electrons to see how such atomic knowledge is gained. So I derive it in lecture, and ask for opinions ("tough"); then wait a week and derive it again in lecture, then in class, then in an assigned problem. An offer

Now try tabulating the main topics, beginning at the end:

TABLE OF TOPICS OR BLOCKS

Nuclear Physics
Electric and magnetic fields
Electric circuits, charges, magnets
Energy and energy-conservation
Heat as molecular motion

Cyclotron
Radioactivity
Ions and atoms
Simple chemistry
Molecules

Kinetic theory of gases
Discussion of good theory
Newton's gravitational theory; many applications; v^2/R derived and used
History of planetary astronomy
Momentum and momentum conservation
Force, mass, motion: Newton's Laws of Motion

There is my course outline, written *backward* — a healthy way to write any syllabus.

It needs a beginning: I use an empirical study of falling bodies and accelerated motion to set the ball rolling.

Some small topics are covered by reading alone; and at the end of the year a long "reading paper" written on some topic just outside the course (see suggested topics at the end of my book), gives a sense of pride in expert knowledge.

The Function of Laboratory Work

I use laboratory work to teach some topics completely, and to deal with others empirically before law and order are produced in lecture or by reading. This is a slow and very costly way of teaching material-content; but its special benefits in making science genuine to the non-scientist are essential. Laboratory work is discussed in a later section, and mentioned here only as a way of covering some syllabus-items.

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* (cont.) to derive it yet once more brings groans from many and agreement from most that it is now reasonably easy. I point the moral that mathematics is useful and learnable. I have broken the back of the mathematics bogey for some of my students, and I have given an essential formula a sensible foundation.

SECTION (IV). TEACHING AND TEACHING STAFF

Our long-term gains depend greatly on the teachers and their aims; not on some magic difference made by changing from lectures to round-table groups, not on the choice between a formal text and the study of original papers, but on how the teaching does two things: (a) brings each student in direct contact with real physics, as with real physicists, working, thinking and talking as physicists – not as expounders. (b) makes each student learn by his own efforts.

Lectures

Lectures are the most economical form of teaching (in covering material and in cost of staff); and the most dangerous. If we use them to just expound material quickly and thoroughly, we may paint the wrong picture of science, by overemphasizing facts and mathematical methods. Yet most of us have to use lectures, and even prefer to use them, as a way of covering material; and I value lectures for the following as well:

(i) They enable me to set the pace of the course and maintain its progress from block to block.

(ii) I can show demonstration experiments and discuss them.

(iii) I can argue, discuss and raise questions in lectures. I can take a strong stand on some points of physics or philosophy that I consider so important that neither students nor my colleagues should ignore them. I do not expect my colleagues to follow my "party line" on such matters in subsequent classes – in fact I welcome disagreement – but I use the lectures to open up some problems.

So, in my own course I use lectures to cover a large fraction of the material-content of the course, leaving a small fraction to class-teachers (because they need plenty of spare time for their own discussions), and a considerable fraction to students' reading. For some topics, I merely show a few experiments in lecture, then ask students to cover most of the topic by reading. (E.g., Surface Tension, Ch. 6; Bernoulli etc., Ch. 9; Heat and Temperature, Ch. 27; Electrostatics, Ch. 33; Mass Spectrographs, Ch. 38; Accelerators, Ch. 42.) In these, the wise advice to students is:

> "Study this chapter lightly or thoroughly, as you like. Examinations may ask you about any of the material in it – they should certainly offer you opportunities to make use of it – but the harder parts are not worth much study unless you are genuinely interested. In college, you are past the stage of fixed assignments and uniform progress. YOU GET WHAT YOU PAY FOR."

The chapter on Mathematics (Ch. 31) and the final chapter (Ch. 44) are not chapters to be covered by lectures (unless we have an unusually able group of students or an unusually long year). They are for keen students to read on their own.

I wish we could have more of the course taught by reading without lectures; but, to be fruitful in the hands of busy undergraduates, such reading must be followed by inquiring problems.

Lecture Demonstrations

Demonstration experiments are to some extent interchangeable with laboratory work. If we had time, most demonstrations would be more valuable if students did them in lab, or watched them at close range in corridors. But the quick showing and clear discussion of a lecture demonstration can save much time.

Demonstrations also brighten the course with entertainment; but that is a poor objective. The common comment that a lecturer should be a showman is misleading: he needs to discuss science, and show science, not advertise science by a circus performance.

However the course is run, some demonstrations seem to me essential, to emphasize the authority of experiment. Below, I give a list of suggestions, chosen quickly.

SUGGESTIONS OF LECTURE DEMONSTRATIONS

A projectile parabola for analysis.
A test of vector addition of forces.
Guinea and feather experiment.
Demonstrations of Newton's Laws I and II. (see note *on next page)
Conservation of Momentum (with measurements — e.g., as on p. 138 — not just a qualitative exhibit of colliding pendulums).
Galileo's pin-and-pendulum experiment (p. 278).
(If Ch. 6, Surface Tension and Ch. 9, Fluid Flow, are included in the course, they must be illustrated by experiments.)
A model to illustrate the generating of epicycloid motion for a planet's apparent path. (Well worth constructing.)
Circular orbit demonstration (preferably one in which centripetal force is calculated from the motion and then measured directly as a test).
Loop-the-loop (preferably with removable section of rail at top of loop).
Gyroscope, for delight.
Gyroscope, to illustrate precession (p. 326, Fig. 22-20).
Illustration of conservation of angular momentum (turntable).
Some form of "Joule experiment" (as well as in lab — commentary on errors is needed).
Mechanical model of a gas.
Diffusion of bromine (and H_2 or He, and CO_2).
Gas thermometer (standardized with ice and boiling water; compared with mercury thermometer in warm water; then used to measure the temperature of boiling nitrogen).
Gas viscosity and pressure. (Apparatus of Fig. 30-16, p. 454, is difficult to make and very difficult to run with measurements in a lecture; but I believe it is worth the trouble to show Kinetic Theory bearing remarkable fruit).
(If Ch.32, Electric Currents, is not covered fairly fully by laboratory work, some demonstration experiments are necessary.)
A few elementary electrostatics experiments.
Test of Coulomb's Law by hollow charged sphere.
A model of magnetic domains.
"Catapult forces:" qualitative and quantitative. (See sketches in Ch. 37.)
Electron stream in electric field, and in magnetic field.
Radioactivity: counters in use.
Absorption of alpha-, beta-, gamma-rays.
Exponential decay.
Model of alpha-particle scattering (e.g., Rutherford's own model with electromagnets.)
Cloud Chamber.
Photoelectric effect.
Interference of water ripples, and of light waves.

This list of two dozen illustrates my aims: to show physical experiments being done, to show some important phenomena not vouched for by common knowledge, to test a theoretical prediction, and to enable students to share a scientist's delight. For all those benefits, commentary on the demonstration is as important as the experiment itself.

If a colleague enjoys demonstrations and does them with critical comments and stimulating questions, I urge him to do many more than two dozen. I myself do ten times that number in a year's course – ranging from showing a meter cube of plywood (and asking how many kg of water it will hold) to counting neutrons with boron tube+discriminator+ scaler (and asking what we infer from the effects of interposing paraffin and cadmium in different sequences). I make demonstrations an important medium for discussing physics with my students – and that is my only good excuse for doing so many. But, before every demonstration I ask myself "What is this for? What do I expect students to get from this?" and I urge all lecturers to ask that. If the answer is "Entertainment," or, worse still, "It's fun for me to do," we should omit the experiment or run it quickly. Exercising that censorship will itself make the demonstration more profitable, more likely to be discussed. It reminds us to point the moral, to continue the experiment with a problem, or to preface it with one. Occasionally we decide that an experiment is to be shown for pure delight; then, admitting that, we can show it with a good conscience – delight is part of our art. In some of our most important demonstrations, I feel the benefit runs parallel to the Archbishop's remark in Bernard Shaw's "Saint Joan," that "A miracle, my friend, is an event that creates faith. That is the purpose and nature of miracles."

Discussing Demonstrations. Here are some abbraviated examples of my discussions. Note that the dots (...) represent discussion, calculations, etc., omitted for brevity.

(i) Galileo's Pin-&-Pendulum Experiment, (p. 278).
"Galileo based arguments about accelerated motion on the assumption that an object sliding down one hill and up another would rise to the same height. We can test that with a cart on sloping rails, but friction spoils our test. Galileo, using imagination, could pooh-pooh friction and jump to the ideal result – from what I know of him, I am sure he would do that. Yet he invented a frictionless experimental demonstration – almost without friction, a work of genius – and showed it. Here it is. Watch.... The line is horizontal, tested with a spirit level. Watch.... We can also test that by swinging the other way.... A miracle to see... assurance that we are describing nature on sound lines... beginning the idea of energy-conservation. Now I

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* Complicated truck and track methods for demonstrating Newton's Law II are likely to be displaced, in many a lecture-room, by the technique of "dry-ice pucks" and multiple flash pictures, developed by the Physical Science Study Committee. The truck becomes a disc of metal or plastic sliding freely on a glass table. The disc moves with practically no friction because it rides on a thin layer of CO_2 from a store of dry-ice that it carries (or even air from a store of liquid air). A single picture is made with several exposures equally spaced out in time (by a rotating shutter or by a repeating flash-bulb). With a Polaroid camera, the picture can be produced as a lantern slide in a few minutes, for measurements that the audience can see. Some form of strang-meter is still needed.

For demonstrations of momentum-conservation, this technique brings an even greater advantage: collisions in two dimensions can be analyzed. Photograph a collision between two dry-ice pucks, both moving (or the bobs of two long pendulums); see that each mass moves with a constant velocity before collision and another constant velocity after; measure the velocities, and show that momenta preserve the same vector total.

will show you how Galileo argued from that to a remarkable new idea..." [Give argument to Newton's Law I].

(ii) Diffusion of Bromine (Fig. 25-10, p. 364).
"... when I break the capsule, the dark red liquid bromine will evaporate to brown bromine gas, or rather vapor. Watch.... Why only so far? ... yes, air molecules are getting in the way so that the brown bromine molecules make only slow wandering progress. Then let us try taking out the air first ... From the sound of the pump, 99% of the air is out: cut off the pump. Ready?.... That shows the speed of bromine molecules."
[Note: This experiment is worth while for pure delight and a qualitative hint of great speed; but it can also yield an estimate of molecule size. Some time later in discussing mean free path I mention the 'drunkard's walk' (see Gamow's '1, 2, 3, ...Infinity') and give the result. Then I show bromine diffusing in air again:] "Look at the brown vapor now. We will leave it to diffuse for 10 minutes and try to estimate the MFP.... Now [10 min. later] I want you to judge how far the bromine has diffused, by telling me where it looks to you half-brown, half as dense as at the bottom where there is still some liquid. As I move my finger up from the bottom, say NOW at the right place... Well, the average NOW was about here, 10 cms from the bottom. So the average distance travelled by bromine molecules in 600 secs. is 0.10 meter. Suppose their average speed is v meters/sec. and they have mean free path x meters in air. Then in 600 secs. they travel a total crooked distance 600v meters and make 600 v/x collisions. So the drunkard's walk result (which I will derive afterwards for any who wish) tells us the net travel of bromine molecules should be $(x)\cdot\sqrt{(600v/x)}$ on the average. To find x from our measured 10 cm, we need to know v. Ask the chemists for relative masses, and use our measured speed for air molecules, 500 meters/sec... bromine speed is about 200 meters/sec. Then ... x is about 0.8×10^{-7} meter. Compare this with.... Very rough, but...."

(iii) Catapult-Force Law (Ch. 37.)
"We must know the catapult-force law; because we shall use it in measuring electrons' charge/mass ratio and in explaining the working of mass spectrographs, cyclotrons, etc."
[Make tests with apparatus A Fig. 37-15, page 620. After trying various currents continue as follows.] "We have only made a guess of the $1/r^2$ factor. Now we will give it one test, using these two coils... same current.... The force is just 12 grams-weight. With the smaller coil of two-thirds the radius, what force do we expect...hope for? — with the same currents?.... Yes, 18 grams-weight. Hang 18 grams load on the moveable coil; turn on the currents...almost balanced. That's the best we can expect. You must take my word for it: this relation has been tested many times."

(iv) Velocity of Air Molecules (Fig. 25-9, page 364.)
"Our theory has predicted an expression for air pressure. We assumed that gas molecules are in constant motion, probably moving fast; and now we can use our result to estimate the speed of the air molecules in this room, from simple measurements..." [give algebra]"...So I shall measure the pressure of the air and I shall weigh a sample to find the mass of a measured volume ... Barometer 0.76 meters-of-mercury multiplied by density 13.6 times density of water, which is...? ... 1000 kg per cubic meter. Then pressure is

> 0.76 x 13.6 x 1000 and these are meters times kilograms per cubic meter, or kg-wt./sq. meter. We used Newton's Law II in our prediction; we must measure p in absolute units. Therefore multiply by field-strength, 9.8 newtons per kg, and we have pressure = ... Multiplying out gives just over 100,000 newtons per square meter. What did you find in your own lab experiment? Now I shall weigh this flask full of air, then empty.... To find the volume of air taken out, let water in. Watch the fountain. Never mind a bubble; I am still measuring the volume I did pump out. Here is the water's volume.... Now we can calculate v^2 and thence v .... So v = about 500 meters per second; more than 1600 ft per second, the speed of a fast rifle bullet.
>
> Here is theory paying back information about its own assumption. The molecules of this air are speedy, if our whole picture of a gas is correct. Here, as often with theory, the result we get is conditional on the theory. Only if we trust the theory can we trust the result – sometimes a result does not even have any meaning except in terms of its parent theory. But if we do trust the theory the result gives us new details of its picture. I do trust kinetic theory; and, furthermore, in this case I can check it. I can compare this velocity-estimate with a direct measurement. Here is a model of Zartman's experiment for...."

One word about difficult demonstrations that may "fail." We damage the reputation of science if we cheat in a demonstration, or if we slur over one that fails with some vague excuse such as "experimental error." And we do equally great damage if a demonstration fails and we repeat it again and again until it succeeds, and then ignore all but the success. (None of us would say in lab, "Repeat the experiment until you get the right answer.") Therefore, many of us hesitate to show a difficult demonstration that may fail; but I think that is a pity. Let it fail; admit the failure gaily, and point out the difficulties and probable reasons for the observed behavior. Then stick to the observed behavior, as what did happen; but also say clearly what other experiments have shown instead.

The audience may take a gleeful delight in the lecturer's pain over a failure. I sometimes forestall that added distraction by consulting the audience beforehand:

> "This is a very difficult experiment to carry out (in public) (with this rough apparatus) (on a scale big enough for all to see). If it succeeds it will be a delight to see; but if it fails you will see nothing. And it is likely to fail. Do you want me to try?"

Then we have the audience on our side, ready to enjoy success or sympathize with failure.

Classes

If non-scientists are to know and understand physics, they must learn something about physicists and the way they do their work – best of all at first hand. So class meetings, small groups with a good instructor, make a very important contribution. If we call our classes quiz sections and put a young physicist in charge with no clear instructions about his work, classes may degenerate into tutoring sessions or into squabbles about quizzes and marks. So, in my course, I welcome good physicists as class instructors, ranging from my Chairman, who sometimes takes a hand in the course, to the newest Instructor – and occasionally a Graduate Assistant with a taste for philosophy and an exceptionally flexible mind. I say to my Chairman, each year: "In assigning staff to my course, please give me teachers who will enjoy trying this teaching, if possible a philosopher or two; people who will enjoy encouraging argument and critical thinking, people who will go into classrooms as sincere scientists." In practice, it is usually easy to find a good staff.

Sometimes a young graduate student comes nearer to the flexible attitude than a professor: but sometimes the senior man brings the ideal philosophy and feeling of confident immersion in his field. Not everyone is suitable: a clever problem-solving tutor can wreak utter ruin, although some say he is good with engineers. I used to think that among younger teachers an experimental man is safer than a theoretical one — the latter being more likely to look down on elementary teaching. But recently some of my best teachers, in lab and class, have been young theoretical physicists who have found that teaching too is a field of intellectual problems. Incidentally, teaching in this course leaves its mark, in attitudes and techniques that persist.

Having gathered my staff of class teachers, I say to them:

> "Your students are non-scientists. They are well-educated, intelligent young people, but this is their final science course - that is, unless we leave them so delighted that they want to go further. This is their only chance to meet and talk with a good physicist face to face. So please respect their interest and their questions. If they raise a question, chase after it, answer it, and encourage discussion. If a chance remark leads to something interesting in your own field of work, let yourself go, dive in with enthusiasm, talk; explain, and discuss. Do not talk down to them, but talk with them as fellow scientists. Never mind if this plays havoc with the syllabus. In this course, topics can wait, or be shelved forever. The important thing is to have the students understand science and know and like scientists. This meeting in your small class group offers a glimpse of scientists that cannot be provided by lecture or laboratory or even reading."

New instructors do not believe me. They are sure they must try to follow the syllabus. So I offer them an outline of what I plan to do in my own class — though I seldom get it done — as an insurance against stage fright, and as a coordinating guide in case I have spare time. But when an instructor comes back and says, "I never got to the inclined plane; they started arguing about the speed of light." I say, "That's good;" and after a few weeks he believes me. Sometimes class and instructor disappear to a research room, and then I know there will be success.

But what about the syllabus? Well, first of all, topics can be omitted; it is a block-and-gap course. If keen class discussion, where students and teachers match their interest in science, can build a vivid sense of science to hold the blocks together, that is far more valuable than a few overlooked blocks. Second, lectures can maintain continuity; if classes miss an important topic, I cover it in lecture. Third, we assign weekly problems designed to promote thought and raise questions in preparation for later topics. Students' answers go to class instructors to be read and given a rough grade. These weekly assignments influence instructors' interests, and make students raise problems, thus tying classes somewhat to the syllabus. In fact, once the course is running, the weekly problems keep class teachers too busy. Again and again, in staff meetings I have to say,

> "Please do not spend more than half the class-time on weekly problems. Most of the good is done when the student first tries the problem. Of those who get an important problem wrong, courageous students will gain a lot by getting it right on their own; and others who cry to have it done for them will not gain. There are students who need to have the problem done for them but only once — if you go over the same problem several times the subsequent yields are too small to be good for progress."

As general preparation for his work, I suggest to each new instructor that he should read Butterfield's "Origins of Modern Science," and I ask him two questions: "What should we try to give these non-scientists?" and "What are scientific methods?" I accept their answers to the questions; but, knowing that I myself have not finished answering them, I expect the questions to remain and influence my colleagues' teaching.

A few pieces of teaching play such important parts in the course that I ask all class instructors to reinforce my lecture-teaching by repeating the material – in their own style – in class. Examples: the derivation of v^2/R; the cyclotron algebra. And I ask all instructors to discuss, sometime in class, the meanings of 'good experiment,' 'good theory.' In my own class, I discuss 'good or successful experiments' about half way through the year, when students have had time to form new opinions after their first answers at the beginning of the year. I collect suggestions of characteristics of good experiment from each member of the class, and note them on the blackboard commenting indeterminately on them. Not until the next week will I give major criticisms, such as, "Everyone seemed to have left out one characteristic: PLANNING." Even then I never carry my summary to a definite didactic conclusion – I want students to go on thinking.

Weekly Problem Assignments

I assign a selection of problems each week, expect written answers to be handed to class instructors a week later, a day or two before the class at which they will be discussed. These problems keep the course running, students learning, and classes discussing. They are neither routine tests nor busy-work to waste students' time but an essential learning mechanism. So I have constructed and chosen my problems very carefully, keeping in view the whole syllabus, past and future – and its aims. I choose these weekly assignments from the problems in my book – or, rather, I have printed my assignments among the chapter-problems there.

Where a problem is essential to the next stage of teaching inside a chapter, I have printed it in the chapter's text rather than at the end. (Some of those problems that seem most important in the teaching sequence have been marked with a large *. The marking has not been carried through consistently; and there is no explanation of the meaning of those *'s in the book! The * should be regarded as a warning that its question offers important essential teaching.)

At the beginning of the year, I discuss the importance of assignments with class instructors and urge them to give considerable time and trouble to reading students' answers and writing comments on them. The comments should be matters of physics, not grades. Any trivial estimate such as "good," "o.k.," or "bad" should suffice as a mark. Those grades should in turn add up to a small contribution to final grades, to encourage diligence; but students will find that the main value of assignments is for learning – which will be tested by examinations. For students to learn with long-term gains, our correcting of these weekly assignments is an essential major part of our teaching duty.

In inviting my colleagues to contribute assignment problems of their own, I say, as I said to myself originally,

> "These problems serve some mundane purposes: to compel reading and general diligence, to guide students and staff along the syllabus, to offer practice for examinations. But their main functions are to promote thinking and to enable each student to learn by his own thinking and argument. Therefore hesitate to assign numerical problems that encourage mere formula-mongering and parrot-learning. They give science a bad name. If you are inventing problems, look ahead to the later topics; supply plenty of information and ask leading questions. Here are some examples:
>
> (1) (after first experiments on vertical free fall): Drop a ball in a steadily moving train. What would you observe? What would a man sitting on the hedge and watching through the windows observe concerning (a) the ball's vertical motion, (b) its horizontal motion? Now suppose that instead of being in the train, you stood still and threw....
>
> (2) (toward the end of the course): Alpha-particles from radium can be shown by field deflections to have two electron charges. A stream of them from a speck

of radium can be caught in a metal can, and the total charge measured. Then the same stream can be fired at a Geiger counter. What important atomic measurement could be derived?

Sometimes we ask more general problems to lead to discussion. Here are examples:

(3) (about mid-year): In your laboratory work, you sometimes throw out a measurement as "wrong," and do not use it. Is this good or bad? Discuss with examples.

(4) You have seen demonstrations illustrating Newton's Laws of Motion with a truck pulled along a level track. Now suppose the experiments are repeated inside a railroad train (a) at rest, (b) moving steadily, (c) accelerating. Would you you still find Newton's first and second laws reliable summaries of behavior? (This question gets most students into difficulties and produces class discussion that can lead toward General Relativity. We soon have an imaginary carpenter fix up the interior of the train on a tilt so that the simple laws again hold.) [Ch.7, Probs. 28 and 29, page 133.]

(5) Scientists sometimes label one experiment good and another bad. What would you say are the characteristics of a good experiment? (This produces many answers according to the stage of the course. Neither students nor staff agree on unique answers that are the 'right' ones. We insist that though there are some wrong answers, there are many right ones, all of which we accept.)"

Tests and Examinations

Examinations are discussed in a later section; but, continuing the remarks above, here is what I say to colleagues about preparing tests and examinations:

"Look at the weekly problems. Listen to the atmosphere in laboratory. Think what you would like your own brother-in-law to retain as an attitude toward science. Ask questions that use solid science but also require thinking. Try to test genuine understanding rather than parrot-learning. Start with a few simple calculations to cheer up the formula-mongers who are still with us. [The high schools, and the preparatory schools have done their work, and with some students not even a year will undo it.] Then a few easy qualitative problems to comfort the credit-adders [there again, school]. Then ask the real questions. Some can be short; e.g.:

Two electric lamps, A with clear bulb, and D with a 'Daylight' bulb of bluish glass, have identical filaments and are run on the same voltage.

(a) How will their power consumptions compare?
(b) Will lamp D give the same amount of light as A, or more, or less?
(c) Give a reason for your answer to (b).
(d) If the two lamps do not give equal streams of light what happens to the difference? Explain fully.

We should set some long questions; e.g.:

Describe the working and use of a cyclotron.

Some should be vague; e.g:

What is meant by good theory in science? Discuss examples.

I will show you how the latter can be graded; and you will find that the scheme works."

Laboratory

Laboratory work seems to me essential in a course like this, for genuine contact with experiments, and for long-term gains in appreciation and understanding. I am not equipping future physicists or engineers, so I do not value the laboratory for technical training. Nor do I value it for the startling agreement with the text that a well-rigged cookbook can yield. But, for many students, the firm basis of science in experiment is never clear until they do their own laboratory work. For others it is too optimistically clear, and they too need to work in a laboratory. All need to learn the delights and sorrows of experimenting if they are to understand the work of scientists: I doubt if the average freshman can gain a real feeling for scientific experimenting – with care and ruthless honesty, and clever inference – by reading the records of great scientists: he needs to use his own hands. For such benefits there must be plenty of time, few instructions, freedom for each to try things on his own, and quiet sympathetic instruction. By taking the time for good experimenting and discussion, we cut our laboratory syllabus to about half that of an orthodox course. Instructors are delighted with the relief of pressure; and students find the laboratory demanding but profitable. The equipment is simple: cheap springs for multifarious investigations, pendulums for a three-week empirical workout. Hearing the latter, critics complain that we do ungenuine "discovery experiments." Neither our instructors nor our students are so stupid, or so dishonest. We all know the pendulum laws were discovered long ago; but students are happy to try to wrest such laws from their own experimenting.

Only a few of our experiments are "empirical investigations" but these are the ones that leaven the course. As an example, here are details of the "Springs" investigation. Each student is given several cheap spiral springs and asked to find out all he can. We give enough weights to ruin the spring; but we give practically no instructions, beyond suggesting observations of stretch "as well as other experiments you devise for yourself." The first afternoon is rather dull and uneventful; most students try loads and stretches dutifully. Those well trained in school often stop at the Hooke's-Law limit and say "My spring has gone wrong." Those who did no physics at school are better scientists and push their investigation to the bitter end, learning more about springs, about experimenting, and even about metaphysics. By the second week a number of projects are under way: creep, torsion, effects of heating and cooling, compression, comparison with other springs, and even oscillatory motion of a load (surprise). We provide occasional encouragement and do our best to meet every reasonable demand for equipment. We often have a "research-council" meeting of the class after two weeks, to pool methods and results; then we continue one week more. The yield in such laboratories seems to grow exponentially. If only the teaching staff has patience, later weeks of this and other "open" experiments will pay off in interesting results, keen experimenting, and a delight in science.

The teaching staff of such laboratories should be wise physicists and good finders of equipment, but they need not be numerous. If students are to think and work on their own, we do not need many Instructors for discipline or for exposition. In the laboratory itself, one Instructor and one Graduate Assistant can suffice for 40 students (except in electrical experiments, where circuit-checking cries for more staff). Most class teachers take a share of laboratory time; but, since they have a heavy load of problem-assignments to read, they receive only a few reports as a sample. Most of the students' lab reports are read by the Graduate Assistants, whose only teaching work is in lab. On that account, I welcome extra staff, because critical reading of students' reports is a heavy task. At the beginning of the year, I say to all who teach in lab:

> "You are host to young people who come to do real, though unfamiliar experimenting. Make each feel that he is a 'scientist for a day.' Consult seriously over difficulties, as a fellow researcher, not as omniscient teacher. Respect their needs, and ask their judgment. If they ask for extra apparatus, try to provide it without question. If they ask: 'Is this right?', 'Will this do?', 'Is this accurate enough?', reply with a question: 'Will it answer your problem?', 'Do you trust it?', 'What accuracy do you want?' Let them make mistakes, and learn from them. Give them time to make the experiment go with their own help, not yours, and they may learn the delights of

> experimenting. Encourage them to face difficulties honestly, so that they learn the limitations of science and the sorrows of experimenting. In general, avoid interrupting (except for matters of safety), and avoid answering questions, except to reply by another question; or, when suitable, just answer 'It's your experiment'."

Of course such direct sermonizing would no more teach young instructors to change their ways than exhortation teaches anyone to be virtuous. My actual procedure is to start with this admonition, then teach in laboratory myself, remaining silent and asking questions loudly enough for my colleagues to eavesdrop on me. They soon discover my advice was serious: I do want them to be silent without being dumb, to encourage experimenting without giving away the answers. They learn to begin the session with no detailed instructions — "minimum cookbookery, maximum inadequacy" is my motto for laboratory manuals — and then later in the day gather the whole group together for a "research-council discussion" of accuracy, methods, results, improvements, further experimenting.

I discuss with Graduate Assistants the great importance of laboratory work and their teaching in the course. I explain how, in laboratory, they can promote good experimenting by offering an occasional suggestion, finding some extra apparatus, watching and giving a needed word of praise. They have the intellectual problem: how to reply with a question — the best question — when a student asks for help or advice; how to teach by encouraging students to solve their own problems. Then when they come to read and mark reports they have their chance for active important teaching. I ask them to think out what benefits they would like each experiment to provide. I remind them that long-term benefits do not come in a rush. We might expect an 80% yield if we ran an experiment for training in techniques; but we must be glad of a 5% yield in a sense of understanding — we must be content if only one student in twenty is fired with delight by one week's experiment and gains a lasting insight.

Preparing for the Teaching of the Course

I discuss the block-and-gap structure of the course with all my colleagues before they start teaching it; and I urge them to read the first eight chapters, and Ch. 26 on Energy, before the course begins. Then I say to myself and all who teach in the course:

> "Look ahead to later topics. Then, if signs of them crop up in earlier discussions, spend time happily laying down needed foundations. When tempted to treat some topic which has neither later uses nor special philosophical value, try to avoid it. Constantly remember we are teaching non-scientists. More philosophy (in the sense of simple thinking about our work) may be better than an extra fact. Ask yourself two questions often, 'What are we teaching science to these students for?' and 'What are scientific methods?' The answers to these two questions are not fixed; they will shift and grow in all our minds as we brood on them, and as we teach; and in this progress lies the key to the health of our course and the happiness of our students as young scientists despite themselves."

A Word to Administrators

To Deans and other administrators who sponsor such a course as this I say:

> "This course aims at lasting benefits for non-scientists: ability to use science and deal with scientists, and an understanding of science as part of the intellectual background. To have any hope of achieving such aims, we must restrict our topics, and even our field of topics. So please do not press for tidbits to be added to the syllabus.*

Laboratories, although they cost most, seem essential; many of our students must learn by doing. I believe only the abler ones with a taste for history can replace laboratories by reading original records. However, laboratories in this course need fewer instructors. For much of the year, half as many staff per student can move silently round a good laboratory and not answer questions.

Instructors for class and lecture must be people who are sure of their knowledge; not 'trained teachers' who pour it out with unwise force and clarity, but sympathetic scientists with the self-confidence to behave as temporary agnostics."

To All of Us Who Teach

Think of the long-term benefits that you hope students will gain from your class, your lab, or from any other educational activity. Appreciation, understanding, wise knowledge; these come slowly, inspired by one experiment, helped by a stray comment, started by an interesting problem, generated by a student's creative writing. We must be content with a small yield from our teaching. A commercial chemist manufacturing, say, benzene from raw materials may expect 85% yield. Another, synthesizing penicillin, will be glad of 2%, overjoyed by 5% yield. We may expect a "benzene yield" from teaching dates in history or formulas in physics – 85% of the class remember them, or the average student remembers 85%. But, in the long-term gains we seek, we must be glad of a "penicillin yield." One student in 20 is delighted by bold extrapolation to guess new physics this week; another takes a scientific argument to heart next week; one lab experiment leaves a permanent mark in a few students' minds.... This is slow progress, but it grows, and spreads and lasts.

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[*] Some administrators who are non-scientists show strong anxiety over the omission of topics or sections of science, lest their course be compared unfavorably with courses elsewhere which include that material. Others, guided by their own reactions to science, shy away from their fears and advocate commentary-courses in history or philosophy – which can no more teach young people to understand science than a guide-book can substitute for foreign travel. Scientist administrators usually escape these fears. one of the ablest I know said, in commenting on course plans, "For non-scientists choose a few topics and teach them well, as science." Although himself a chemist, he added "Physics seems to provide a better field than chemistry for this, because so many elementary chemical experiments have to be adjusted to give simple results." To that I would add, "and physics provides earlier opportunities for reasoning; requires less collecting of facts, less memorizing, before scientific reasoning can begin."

"Earth science" seems to be a special temptation to administrators, as a candidate to be added to physics courses for general education. Earth science by all means as the science to be sampled; but a mixture of physics and geology seems to me to skip to and fro over too much ground when we want to exhibit both continuity of scientific thought and depth of scientific knowledge.

SECTION (V). A SPECIMEN SYLLABUS AND ITS TEACHING

It seems to me there is no one right syllabus, no unique choice of topics better than all others. However, we can get some guidance from students' interests and from our own aims. For example, students expect a physics course to teach them about atoms and nuclei; and teachers would like to do that, if they can give an understanding of such physics. Again, those students who bring weak mathematical tools (as many non-scientists do) will gain more understanding from topics that use little mathematics than from to topics that are essentially mathematical.

Teachers considering their aims for a course will disagree over pieces of information that they think desirable or important; but will often agree in classing some topics as rich and others poor, in contributing to well-understood science. In the latter respect, many of us regard hydrostatics as poor, and planetary astronomy as good.

So, in describing my own syllabus I offer it only as an example. In my book I have made expansions to allow for some other choices of syllabus; but no book could provide for all good choices and yet teach thoroughly.

In making my own syllabus I had the following aims in mind:

Knowledge.

(a) Students should finish the course with some well-understood knowledge of "atomic physics," in particular: properties of electrons (e/m, e, and relativistic changes), mass-spectrograph and isotopes, nuclear atom model, radioactivity and nuclear energy. A discussion of wave:particle behavior should take an important place at the end of the course; but, to make sure enough background of knowledge had been provided, that would have to come at the very end, perhaps as reading after the end of formal teaching.

(b) Students should have some acquaintance with force and motion, momentum changes and momentum conservation, forms of energy, gases and molecules, householders' electricity.

Understanding of Knowledge. To give students a feeling that they understand what they have learned, we must provide both careful teaching and clear explanation of the knowledge underlying the topics studied. Thus before we teach radioactivity and nuclear atom-model, we must discuss molecules, illustrated by kinetic theory of gases; electric and magnetic fields, and the motion of charged particles in them. And before we discuss those topics we must teach some elementary electricity and magnetism, and some dynamics. So most of (b) above is demanded for understanding of (a) anyway.

Understanding Science. Students need ideas — not a single view but discussions of views — concerning: laws in science, the relationship between experiment and theory, and the strong distinction between theory and simple hypotheses. For these benefits students must be carried through actual examples, not just harangued or given pat definitions. Hence my choice of history of astronomy (for growth of deductive theory); and magnetism (to show theory yielding language); and kinetic theory of gases (for rich predictions and promoting of understanding).

Understanding Scientists. For this I trust to (i) good instructors in class, (ii) laboratory work,* (iii) reading papers.

SYLLABUS

With these aims in view – remembering, too, the strong warnings about transfer of training mentioned in Section (II) –I chose the following syllabus for my book and its course:

PART ONE. FORCE AND MOTION

Introduction. We use "falling bodies" as an example at once. Then we discuss scientific reasoning, meaning of "explanation" in science, empirical approach. Also discuss units, accuracy. This gives students a sample of the flavor of the course and raises some questions (e.g. "What is explanation?") which will remain alive throughout the year.

Vectors, force and motion, momentum. This is solid bookwork, with no good use, in the eyes of most students, except for the part it will play in astronomy and atomic physics. (Students have no urgent sense of the need for Newtonian dynamics and the great reform it made. In a way, Newton's Laws would be better postponed till needed in astronomy: a harder arrangement for most teachers, but happier for students).

Newton's Laws of Motion are treated as if extracted from experiments. They are regarded as summaries of behavior that incorporate some definitions. Force is treated as intuitively familiar; and mass is derived, both qualitatively and quantitatively, as a description of inertia. Momentum-conservation is tested by experiment and then set on a high pedestal as a general law.

Aside from their general part in developing physical knowledge, Newton's Laws are used essentially in some later topics of the course: $F = Ma$ must be applied to ions moving in electric fields, so that measurements of e/m make sense; $F \cdot \Delta t = \Delta (Mv)$ is used in kinetic theory; $F = Ma$ must lead to $K.E. = \frac{1}{2}Mv^2$ or the treatment of energy will remain a descriptive muddle; $F = Ma$ must combine with $a = v^2/R$ in treatments of planetary motion, magnetic deflection of moving ions, cyclotron, and measurements of electrons' e/m in laboratory. But all those uses need only a simple acquaintance with $F = Ma$: they do not justify a long hammering treatment with profuse examples and problems. We are tempted to spend too much time on all this, from old habit. Actually, the quicker we go through PART ONE the better. If the treatment of Newtonian dynamics is too light, it will gather the needed strength when it is put to use in later parts.

In laboratory we ask for empirical investigations (e.g., falling bodies, springs, pendulums) to give a feeling for experiment, and to open up questions. The investigation of accelerated motion and the experiments on springs both raise important questions about laws and knowledge in science. We begin to show relationships between experiment and theory.

PART TWO. HISTORY OF PLANETARY ASTRONOMY: as an example of growth of theory.

For this purpose, the story should start with the earliest stage of gathering empirical knowledge and belief in magic: and ideally it should end by showing the successes of Newton's theory in detail, not just by naming them or talking about them. Therefore the later part of this story needs a working knowledge of dynamics, so that the "explanations" make sense. And, now or earlier, centripetal acceleration must be discussed carefully.

(The function of this part of the course must be explained to students beforehand, or they are apt to mistake it for an uncalled-for digression into astronomy for astronomy's sake.)

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* One could list a legion of special aims for laboratory; but that might stifle the broad objective. (An example of a small but important aim, probably best fostered in lab: to gain an understanding of interpolation and extrapolation and their use in the growth of science.)

PART THREE. MOLECULAR THEORY AND ENERGY

Simple kinetic theory of gases sets the stage for atomic physics, by giving some familiarity with molecules. But it does not give the course a "block" of lasting value unless it is carried to a fruitful stage. So we offer two chapters: first a bare derivation of the pressure-prediction; then, after a necessary pause to discuss energy, a second chapter uses equipartition to provide a measurement of molecular mass, and shows how we can estimate molecular mean free path and thence measure molecular size. Such detailed discussions must be offered, or kinetic theory will appear as a stark derivation, begun and then left unused; but for many students much of this extended treatment must be relegated to reading.

Meanwhile Energy has been delayed until now, for several reasons:

(i) to keep kinetic energy well separated from momentum. (To some physicists that seems silly. To most experienced teachers it is a helpful trick.)

(ii) to avoid presenting mechanical P.E. + K.E. as the sole participants in conservation — which would make a great Principle look like a rigged scheme. With the help of kinetic theory, thermal energy is easily pictured and brought into account.

(iii) electric-circuit experiments in laboratory contribute to the energy story at this stage.

Many students bring with them from school science courses a blind-trust in energy as an explanation-panacea framed in catch phrases such as "you can't get something for nothing." Now is the time to start afresh and show what we mean by energy, how we measure it, and why we hold that it is conserved. It seems wise here to revert to the 19th Century definition of work as transfer-of-energy and not itself a form of energy. Then the confusion between "work-done-by" and "work-done-on" disappears. Then we always word our statements about work like this, "the work is so-many joules transfer from potential energy to kinetic energy." And we treat heat at first as caloric measured by heating water; and then link it to mechanical energy by a wealth of varied experiments — in that way Joule's work keeps its great historic value instead of being debased into being called "mere measurements of the specific heat of water." Besides energy, there are brief discussions of heat and temperature and of power.

The discussions of both energy and kinetic theory are intentionally long: if they were either superficial or condensed the yield would be poor. Both are important topics in their own right, but the active teaching of them need not be spread over many lectures. Reading and problems can continue their study long after formal treatment.

It is essential to give students a lasting understanding of food and fuel energy, nuclear energy-changes, the possibilities of machines and the impossibility of perpetual motion — altogether, the First Law of Thermodynamics. If possible, students should gain some idea of the Second Law; and, in kinetic theory, a glimpse of quanta. These are far more important than temporary training in computing an impossible temperature-rise when a lead bullet is stopped by a wall.

PART FOUR. "ELECTRICITY AND MAGNETISM."

A modern householder should be acquainted with volts, amps, ohms, kilowatt-hours. Yet many a student who studied physics in high school fails when asked to "add a voltmeter to the circuit to measure the power used by the lamp." And some who have not studied physics are ready to believe that a smaller current comes out of a resistor than goes in. So, if time and equipment are available, a series of laboratory experiments in current electricity will make a welcome contribution of information. Then problems on power lines etc., make good energy discussions. For good learning, students should puzzle out their own circuits, and not be spoon-fed with ready-made diagrams. Starting with simple batteries and lamps this laboratory work can soon progress to diode and triode tubes and put them to use — with electrons and electron guns appearing as delightful surprises. If laboratory is not available, most of this can be left out, provided demonstrations teach the following: the idea of charge, and the coulomb as a unit; potential difference, and the volt defined as a joule/coulomb; electron streams from hot filaments, and electron guns.

Half a century ago, electrostatics formed an impressive sprawling foundation for electrical teaching; later it was sensibly condemned as largely irrelevant. (Electrostatics experiments were still recommended for schools "because they cost so little." In fact they cost education a lot because unexpected charges and unwanted leakage gave electricity an air of witchcraft.) Now, however, electrostatics is again important: electric fields are essential tools in atomic physics.

Although a long chapter on electrostatics is offered (for teachers or students with special interests) the only essentials for later studies are: Coulomb's Law, the idea of field strength; the pattern of the electric field between parallel plates; and the expression (p.d./distance) for the strength of that field.

Magnets and magnetic fields would be important in a course training future physicists for further courses, but here we need only a simple acquaintance with patterns of magnetic fields for later studies of charged particles moving across a field. Science courses at school have usually provided general knowledge of magnetism, so magnetism can be left to a review by reading.

A theory of magnetism — in simple 19th Century form — can prove very valuable, by showing how theory can increase our understanding by enriching our language. Even for that value alone, I include some teaching of simple magnetic theory.

In all studies of atomic physics we trade on some knowledge of chemistry; and students who never studied chemistry will be at a disadvantage. Current electricity gives a rich link between physics and chemistry, so this seems a suitable place for a simple chapter of chemistry to serve as reference reading for those students.

Thus this Part on Electricity and Magnetism contains useful material for reference — and students should probably be asked to read all of it — but, for active teaching, this is the most compressible part of the course. It deserves quick treatment to give the necessary minimum tools.

PART FIVE. "MODERN PHYSICS."

Now at last we are ready to explore some parts of modern physics. And this should not mean "now, in the last month of the year,...." Earlier parts of the course should have been trimmed to leave much more time than that; and modern physics should have already entered those earlier parts wherever possible. (For example, a problem on electron streams falling in an electric field should come with the earliest problems on projectiles falling under gravity.) Later we use fields to compare electrons with positive ions, and measure e/m for each. Then we can show how Millikan measured e. Thence we can find m. Atomic physics easily becomes just hand-out teaching, and students lose their sense of scientific knowledge. So, to convey understanding these measurements are presented in the form of problems.

Electric-field deflections tell us e/mv^2 for charged particles. To find e/m we must make another measurement as well: either v measured with a chopper or e/mv measured with a magnetic field. The chopper, or time-of-flight method is used in one problem — and there is talk of using it more in elementary teaching — but we need magnetic-field deflections for several purposes, cyclotron, some mass-spectrographs, a laboratory experiment. So we develop a semi-experimental discussion of the Lorentz force, the force exerted by a magnetic field on a charged particle moving across it. This is the hardest chapter in the book and probably the least satisfoctory for simple clear understanding. (Some readers will dislike my choice of approach. There are many other treatments but none that seem much simpler, except those which simply announce a formula. My treatment, clumsy though it looks, gives students some feeling of reasonableness.)

With analysis by electric and magnetic fields established, students can see how we learn the properties of electrons and ions, and alpha- and beta-rays; they can understand the working of mass-spectrograph, cyclotron, etc. Knowing the source of atomic knowledge endows that knowledge with quite a different quality from that of unsupported information.

Radioactivity is described; and the working of cloud-chambers, electroscopes, and counters explained. We make much of alpha-particle scattering as leading to the picture of a nuclear atom. This leads directly on to a review of atomic theories and a discussion of nuclear changes, from natural radioactivity to fission, and the effects of bombardment.

Meanwhile there are separate chapters, which could be omitted, on mass-spectrographs and on accelerators.

Omissions. Whatever topics one decides to omit in a block-and-gap course will receive strong pleas for readmission, particularly those in modern physics. In early trials of this course, I decided to omit wave properties of light (as well as geometrical optics), and to shorten the discussion of quanta to a very brief story. As a result, the wave: particle behavior of both radiation and matter — the essence of most modern physics — was treated with scant justice. Yet the chief reason for that was not mere chance or lack of time as much as the conviction that, unless backed by knowledge leading up to it, a wave: particle discussion would degenerate into mere hand-out statements of results. Students need time, as well as background, to digest such strange ideas. So my remedy has been to increase the chapter on S.H.M. in PART ONE to give some account of waves, and to extend a final chapter at the end of PART FIVE, to be read at leisure. In my own course I devote some active teaching to the photoelectric effect and the idea of quanta; then I discuss waves, wave:particle behavior briefly, with a few words on uncertainty and complementarity. But I do all that with a feeling of uneasiness at having to hurry; and I put my essential hopes on students' reading after the course. I do not feel guilty, because I know that every block-and-gap course in physics must end with unfinished business.

INTERLUDES ON MATHEMATICS

One chapter on elementary mathematics offers help in arithmetic and graphs where some students may need it.

Another chapter discusses, indeterminately, the relation between mathematics and physics, and gives some account of Relativity. There are references to Relativity in several parts of the book, and some students ask for a clearing up of the explanations. This is a chapter for students to dip into on their own.

SUMMARY

(See also the table at the end of this booklet.)

Here is a summary of the way I run my course with my own book as text:

PART ONE.

Treat Ch. I carefully as introduction; then hurry through Ch. 2,3,7,8 for Newtonian dynamics of $F = Ma$ and momentum.

Use Ch. 4 for some of the laboratory experiments described in it.

Assign Ch. 5 as reading to follow laboratory investigation of springs; and Ch. 10 to follow pendulum experiments in lab.

(Omit Ch. 6 and Ch. 9 unless I give a lecture on Surface Tension or Fluid Flow: if so, assign the chapter for reading.)

PART TWO.

Run through Ch. 12 to 20, quickly, following text.

Deal with circular motion carefully in lecture and use Ch. 21 for review and problems.

Treat Newton's work very carefully and fully (Ch. 22 and 23).

At several stages make comments on the growth of development and theory and use Ch. 24 as general reference and review.

PART THREE.

Begin kinetic theory carefully (Ch. 25), using problems for chief introduction.

Later, continue into detail of Ch. 30 but leave some of that to reading.

Treat energy, Ch. 26 and 29 with great care.

Meanwhile, in lab., make simple measurements of heat (Ch. 27), and power (Ch. 28). Then measure "J".

PART FOUR.

Spend six weeks on electric circuits, in lab. (Ch. 32).

Reduce Electrostatics (Ch. 33) to Coulomb's Law and a short measurement of electric field strength.

Limit magnetism (Ch. 34) to a few experiments and a discussion of theory.

In general, do not hurry through Parts ONE, TWO, THREE, FOUR, but do not let them expand. Let students read the remainder of the material of these Parts as they like.

PART FIVE.

Measure e/m and v for ingredients of atoms (Ch. 36,37,38).

In Ch. 37, explain that Lorentz' force discussion is difficult, and ask all to follow it once then learn the result and use it.

Discuss radioactivity at length in lecture and laboratory (Ch. 39).

Describe alpha-particle scattering and assign Ch. 40 for reading.

Use some experiments from Ch. 41 for lab (triode, e/m).

Treat Ch. 42 very briefly or omit it.

Discuss parts of Ch. 43 carefully.

Discuss photoelectric effects, quanta, uncertainty and complementarity briefly; and leave the rest (Bohr model and further discussion of quanta and wave:particle behavior) for reading after the course.

LABORATORY; In the year, we do the following, or less:

Falling bodies etc., (1 week) Ch. 4, Expt. A.

Acceleration ($1\frac{1}{2}$ weeks) Ch. 4, Expt. C.

Pendulum ($3\frac{1}{2}$ weeks or more) Ch. 4, Expt. D.

Pressure, Boyle's Law, Ch. 4, Expt. E (2 weeks, omitting some part).

Test of $F = Mv^2/R$, Ch. 21 ($\frac{1}{2}$ week).

Heat transfer (inferences) Ch. 4, Expt. F(1)-(10), (2 weeks).

Heat measurements, Ch. 27, Expts. A,B,C,(E), (1 week).

Power measurements, Ch. 28, Expts. A,B,C,D,E, (1 week).

"J" Ch. 29, Expts. A,B, (1 week).

Electric circuits, Ch. 32, Expts. A,B,C,D,E,F,G,H,I, (J,K,L), M,Q,R,T,U,V,W, (5 cr 6 weeks).

Triode tube amplifying, Ch. 41, Expt. H, (1 week).

Electromagnetic induction etc., Ch. 41, Expts. A,C,D,E, ($1\frac{1}{2}$ weeks).

e/m for electrons, Ch. 41, Expt. I, (1 week).

Radioactive decay, Ch. 39, (1 week).

Tours of Research Labs at least twice in the year, once early in the first term, once near the end of the course.

READING PAPERS are chosen from the list at the end of General Problems. Each student must do reading and write a paper, usually in the last 6 weeks of the year.

TABLE OF LECTURE TOPICS, READING AND PROBLEM ASSIGNMENTS, LAB EXPERIMENTS

A detailed list, for my own course, is given at the end of this booklet.

SECTION (VI): COMMENTS ON INDIVIDUAL CHAPTERS

The following notes, which reflect my own aims and choice of problems for teaching, are offered as a rough guide in planning. I hope that in actual use of the book teachers will disregard these notes and will be guided by their own formulation of aims and will make their own choice of problems.

Chapter 1. GRAVITY A FIELD OF FORCE

1. AIMS/OUTCOMES

GENERAL AIMS:

To illustrate the general attitude of the course.

To ask questions that encourage thinking about aims, methods, and nature of scientific knowledge; and, even at this stage, to suggest that many important questions do not have a unique right answer.

To start a year-long discussion of meaning of scientific explanation.

To give brief descriptions of inductive and deductive approaches and contrast them, and point out that both are used, often mixed.

To raise some matters early that will be treated later: field, mass, limits.

MAJOR AIMS:

To raise questions of HOW and WHY for falling bodies.

Show experiments on free fall; and describe Galileo's argument.

Mention Myth-and-Symbol expt. and look towards its use in ideas of field and mass.

Discuss meaning of "explanation" in science.

Show accelerated motion, make measurements and tests for constant acceleration.

Introduce M. K. S. units briefly.

ESSENTIAL OUTCOMES:

General impression of a questioning attitude, an intention to think things out and perhaps keep and discuss several answers.

Knowledge that, but for air resistance, all objects fall with the same motion: motion with constant acceleration; so that starting from rest, $s \propto t^2$.

Knowledge that, with fluid friction, falling object reaches constant ("terminal") speed.

Galileo's 3 bricks argument.

Idea of extrapolation to ideal case. Codifying nature mathematically.

1. NOTES

This chapter sets the stage for much of the teaching ahead; but if we spend long on it we shall grudge the time and regret the delay in getting down to business. On the other hand, most students will not gain much by reading informal discussions of philosophy at this stage unless we also treat these matters in lecture or class. So we discuss such things as

Use of experiments. Deductive and Inductive treatment.

Scientists and WHY, HOW, WHAT? Scientific "explanation."

Use of thought experiments.

These would make an unpleasant indigestible hodge-podge if we just produced them as series of short topics in the first lecture or two.. Instead, we keep them in mind as things to comment on while we are treating free fall, accelerated motion, projectiles....

Very early I give short explanation of block-and-gap course and our reason for omitting topics and arranging our course like that.

We show several tests of accelerated motion of a truck running down a hill. At this beginning stage, appeal to experiment is of great importance. We begin with the raw empirical examination of Fig. 1-7 in the first lecture; and in the next lecture we even start the cart with an uphill shove. This method fails to show constant acceleration very closely — since we measure total time between mid-points instead of mid-times — but it shows clearly what we are looking for and it is not obscured by algebra or logic. Then we start afresh: assuming constant acceleration we deduce $s \propto t^2$; then test it by measurements. We remind students again and again that $s \propto t^2$ follows from our assumption by algebraic logic, without any experimental test: then experiment tests whether real downhill motion fits our assumption.

Then as an overall test (in some later lecture) we arrange markers with electric contacts so that the cart makes a short beep of sound as it passes each marker. Students listen, first with markers arranged uniformly, then with quadratic spacing to give a uniform rhythm of beeps. Then we repeat that test for free fall, with expt. of Fig. 1-14.

I show a kilogram, weighed against 1000 cubic cm of water; and I show a meter cube of cardboard; but I leave the density of water to be worked out in Prob. 26.

In an early lecture, I show guinea-and-feather expt. Then, going to the other extreme, I show steel balls falling with constant speed in castor oil or glycerine. (At this stage I make only a brief comment on that motion, suggesting that Aristotle may have been referring to it, and warning that it will have an important use in Millikan's experiment.)

1. PROBLEMS

(As soon as the course begins, I assign the preliminary problems for Ch. 1 and ask for them to be brought to class a day or two later. These are to start students thinking about scientific vocabulary and scientific work. I also assign another batch of problems to be done by the end of the first week. At this time I explain the importance of problems in this course as a method of learning.)

IMPORTANT PROBLEMS:

Preliminary problems 1,2,3,4,6.

Preliminary problem 5 is almost essential for a good start in the course. (In class my colleagues and I also collect spoken answers, and encourage argument. We accept students' choices, and do not give a clear decision of our own except, usually, to condemn Statement No. 8 as unscientific at this stage of students' knowledge — a pompous rigamarole which may later prove acceptable.)

7+8+9+10 (as examples of building a scheme of analysis).

11 (only if it helps demonstration).

12,14,15 (probably necessary as a test of reading).

(13 as alternative to preliminary prob.1)

18 (anticipates discussion in Ch.7. If you believe in "teaching ahead," assign this now).

20 (We get surprising responses; many think acceleration is zero at vertex. We do not at once condemn wrong answers, but we discuss the ideas involved and assign Prob. 21. See note for 21.)

21 (assign a week after Prob. 20. This is intended to illuminate "vertex problem;" but many students find this too hard. For them, we discuss a bank account that starts with balance of $40 from which $10 is drawn out each day, on through a balance of zero, - 10 etc; and we ask whether a graph of balance vs. time slopes continuously or develops a short horizontal plateau at valance zero.)

24 (Assigned after lab work in which students are asked to put error-boxes on graphs. This problem helps students to cure mistaken views (and uses) of error-boxes. The answers we offer later, on an answer sheet, run: "S is saying:
(a) 'Now that I have seen the mess that my plotted points present, I go back on my carefully-thought-out claim of errors. I am so sure that the LAW of a straight line is RIGHT that I will admit my measurements were unexpectedly inaccurate'
(b) 'Well, I suspect I was sometimes much less accurate than I expected.' (And privately to his partner, another engineer, 'Look George, we have to get those points on the line somehow; and at least some of them are accurate.')
(c) 'I am sure that sometimes my possible errors must have been all positive, and sometimes all negative – not by simple chance, but by the action of peculiar demons attached to specific regions of my investigation. I now have secret knowledge of the directions (+ and -) of these special peculiarities."

25 (to start students using M. K. S. units and to introduce Angstrom Units, which will be used a lot in modern physics chapters. Microns will not be used.

For 25 (d) a rough answer to show principle will suffice, about 10^{-4} meter. (Values half this are due to forgetting there are two pages to a sheet.) Students who get 3 times as many atoms as A. U. instead of 1/3 need reproof: "If you were asked in Elementary School how many 3-cent apples you could get for a dollar, you would not have said 300."

26 Answer to (a) is not given in text, and students must know its value.

MEDIUM:

16 produces unexpected discussion. I assign it much later in the course.

19 (to generate a non-physical example of $P \propto Q^2$ and discuss its graphing. Useful preparation for lab expt. on accelerated motion).

22 (Fig. 1-14. Assign only if you are going to demonstrate this.)

26 For calculus students.

30 Should be left optional; then some students will try it and enjoy it.

Chapter 1. APPENDIX A. THE ALGEBRA MACHINE

(This provides derivations needed for Ch. 1 and lab. Students should consult this as soon as they find need.)

1A. AIMS/OUTCOMES

ESSENTIAL AIM:

To debunk the idea that $s = v_0 t + \frac{1}{2} at^2$ etc. are mysterious formulas to be memorized, by showing how they are derived, by algebra or geometry or calculus, from $\Delta v / \Delta t$ = constant.

To show algebra as a useful machine that can re-shape and combine pieces of knowledge, but cannot manufacture new knowledge – at this stage.

IMPORTANT OUTCOME:

Ability to carry through these derivations, preferably using Galileo's geometry, or calculus. (This is neither necessary for future topics nor specially virtuous in itself, but it gives students a good sense of power and an example of the beginning of mathematical physics.)

MINOR OUTCOME:

A glimpse of an "elegant" method in algebra (See (4)).

1A. NOTES

I assign this for study, saying that No. (4) may be left until it is needed much later (for Ch. 26 on energy). I go through (1), (2), (3) in lecture or class, quite carefully, because this chapter is meant for students who find algebra difficult; and if those students do not overcome some of their difficulties or fears now, the course may run downhill with them later. Students who still fear the algebra need not learn the derivations, but the text still serves to show them something important: that the derivations are not matters of mystery but matters of logic. For medium students, Galileo's geometrical method is much the best, because it shows the essential part played by constancy of acceleration. Given as a problem (B-1), it offers them a chance to learn by their own reasoning, and even to share some delight with Galileo. (He is said to have obtained the derivation from Nicole Oresme but he popularized it.) For fast students, Galileo's geometry should be paralleled with calculus.

In going through the algebra I discuss the logic and emphasize two points:

(a) the formulas follow logically from the assumptions; so experiment is not needed to test the logic; but experiment is needed to find whether natural notions such as free fall do agree with logic's prediction for constant acceleration.

(b) distance s is the net distance, not arithmetic total.

1A. PROBLEMS

IMPORTANT PROBLEMS:

A-1 (and/or A-2 for those who know calculus). Discuss answers in class, labelling the areas. Then give diagram, with labels missing, in a test; and ask what difference a growing acceleration, instead of a constant one, would make.

Chapter 1. APPENDIX B. "g"

(Important for its problems, which are really part of the main Ch. 1)

1B. AIMS/OUTCOMES

IMPORTANT AIMS:

To give students practice in solving a few routine problems. (This looks like sabotage of the new course in its infancy, but the problems are there for three purposes:

(i) to comfort students who have been brought up on problem-solving in physics elsewhere, and lure them into some inquiring questions about algebra's part in problems;

(ii) to debunk some fears of algebra, and then to show mathematics as a faithful servant;

(iii) to provide a few useful illustrations and results (e.g., the result of the helicopter series; and the final velocity for a 4 ft. fall from rest).

To show how mathematics acts as a faithful servant. (The problems with multiple answers are important, not for their working but for their final question, "What does the other answer mean?" (See notes below.)

MINOR AIMS:

Students know about measurement of "g" before its value is glibly used in problems.

Students have promise of a better way of measuring "g," lumping many falls together in one bunch, and avoiding troubles from air resistance (Note the cheat in wording that makes this true of pendulums; but do not give the show away to students until the proper time, after pendulum labs.)

Students learn to calculate distances, velocities, etc. for accelerated motion.

Students meet idea of giving boundary conditions to mathematics. If we give too few, we may get several answers.

1B. NOTES

The problems here are more important than the later problems of Appendix A. When the sheets of typewritten problems are issued, I explain that these are intended to teach methods of solving problems which can then be used on other problems that are not dissected. (I make a strong plea that each student should work through the problems on his own, without cooperation: "You cannot learn French verbs by having your room-mate learn them for you.") If, in reading students' answers on these sheets, I find a student has obtained one answer by algebra and a different one by arithmetic and has left them so, I comment, "Inhuman, to leave this conflict." We give students a second chance to explain why there are two answers to Prob. B-6; then at the next class we discuss the matter. After that we assign B-7 to be finished and do not tell students the interpretation. Not until many weeks later do we say that there is a short discussion at the beginning of Ch. 31, p. 469 (but we tell Instructors, so that they can draw on it for their class discussion of B-6).

The measurement of "g" sketched in Fig. 1-23 is easy if one has a relay system for timing trucks on a track. Otherwise some form of multiple flash photography should be used. To do problems on "g" without ever having measured it, even roughly, would be bad for the reputation of physics, at this stage. At a later stage of atomic physics, only too many measurements will have to be taken for granted.

1B. PROBLEMS

ESSENTIAL:

B-3,4,5,6,7 (to learn methods, lose some fear of mathematics, see math as servant). See NOTES above. Also see Ch. 31, pp. 468-470.

B-15 (Idea of "g" relative to frame with various motions: here to be guessed at, as preparation for discussions in Ch. 7 and Ch. 31.)

IMPORTANT:

B-1, B-2.

B-8+9+10+11 (Example of Galilean relativity: barely honest because it is implied in formula to be used.)

B-12 (Numerical value needed for Prob. 8 in Ch. 7, p. 127).

MINOR:

B-13, B-20, B-21.

Chapter 2. PROJECTILES: GEOMETRICAL ADDITION: VECTORS

(A chapter of easy preparation, to be covered quickly, chiefly by reading and problems.)

2. AIMS/OUTCOMES

ESSENTIAL OUTCOMES:

Know, from experiment, the following properties of projectile motion (in ideal case):

horizontal motion independent of vertical motion,
horizontal motion continues unchanged,
vertical motion has constant acceleration of free fall.

Begin to understand Galilean-Newtonian view of motion and contrast it with medieval view.

Familiarity with idea and methods of geometrical addition.

Meaning of "vector," "resultant," "component."

Ability to work through problem like Prob. 18 on electron streams.

MINOR AIMS:

Show use of stroboscopic illumination and/or multiple flash photos.

2. NOTES

In the early years of my course the work of this chapter was done by a short chapter from another text, assigned for quick reading; and a few questions on that reading were added to the assignment. Working carefully through Ch. 2 could delay the progress of the course, without yielding great profit. I now give a short talk about vectors, then assign the chapter for reading, suggesting, "It is written for home study: gather as much as you can from your own quick reading."

2. PROBLEMS

IMPORTANT:

1,2,3, (to gain picture of details of projectile motion by answering problems. In Prob 3 many students miss the point: that we assume projectile not only retains its horizontal motion but also retains its initial vertical motion and adds free-fall distance to that).

4 (student pursues his own formulation of Galilean Relativity).

6 (for components: not self-evident; needs to be taught).

10+11+12 (to teach the essence of vector addition).

MINOR:

5 (makes interesting class discussion).

MEDIUM:

7,8,9 are the delight of most examiners, but I consider them poor candidates for tests because (a) some students find them confusing to picture, in an exam; (b) some students memorize a trick-rule for solving them. However, they serve well as assignment problems to teach a use of vectors.

13, 14 (these continue 10+11+12, for all but very weak mathematicians).

16 (if such a demonstration is shown, this problem, assigned subsequently, bears good fruit. It may be postponed).

IMPORTANT:

17 (merely as introduction to 18).

18 (this reveals unexpected troubles – from fright at electrons instead of baseballs, and over very big and very small numbers. It is important preparation for Ch. 7, Probs. 24+25, (p. 133) and Ch. 36 Probs. 1+2, 5+6, (pp, 606-610). Help with arithmetic of big and small numbers is offered in Ch.11 and its Probs. 8,9).

MINOR:

20 is given only because it appeals to students as a real measurement (Worthwhile to point out that this is how we make an important measurement for moving electrons or ions. This problem makes a good exam question.)

21 (c) is a cruel trick; perhaps worth discussing with class.

Chapter 3. FORCES AS VECTORS

3. AIMS/OUTCOMES

ESSENTIAL AIM:

To establish forces as things to be added, and resolved geometrically. (The other usual aim, to give skill in solving statics problems, leads to a sideline of no particular value in this course. Students can be taught to choose the right trick for each type of problem, without gaining much insight into the nature of physical thinking. Even the three examples given take more time than they deserve. It will do no harm to omit them.)

3. NOTES

Demonstration of Fig. 3-1 is almost essential.

3. PROBLEMS

ESSENTIAL: None.

IMPORTANT:

1,2 (to give practice in thinking about forces as vectors).

6 (to show F/W = h/L for hill; which will appear again in Ch. 7 (p. 114) and Ch. 26, (pp. 379, 402-409), and is referred to in Ch. 19, (p.276).

MEDIUM:

7

MINOR:

8 (amuses some students, worries others; not as impressive as one expects).

Chapter 4. LABORATORY WORK

(This provides some instructions for experiments – but I hope not enough details to spoil the lab. It also provides some reading on: Boyle; "laws of pressure;" radiation.)

This chapter seems to suggest particular experiments and even particular forms of experiment, but those suggestions are offered only as a guide. Any experiment, any apparatus, can be put to good use in an inquiring lab – the essence is in what we say about the apparatus and what we ask, and in our skill in leaving students to do their own experiment.

4. NOTES

The account of transfer of training is there for students to read. I visit every lab group in my course and give a talk that essentially reproduces those notes, because I feel that this helps to set the stage for good labs.

The "analysis questions" for rolling wheel were constructed by a young psychologist teaching in the course. If you try them, you will find them very productive.

The pressure notes and pressure experiments are dull; they are only there as preparation for Boyle's Law.

Fig. 4-10 shows the trick for getting rid of the small air bubbles that stick in a barometer: collect them with a big bubble run slowly up and down. Students enjoy this.

Suggestions regarding graph plotting are given in Ch. 11, p. 202.

In my lab we do Expts. A,B,C,D,E,F, in the first half year spending several weeks on some, omitting part of E and adding the mv^2/R test from Ch. 21.

Chapter 5. STRESS AND STRAIN

(This is not an important chapter, except for its comment on Laws, and the Galilean thought-experiments of its problems. It should be assigned for quick reading after lab experiments with springs are over, or else omitted.)

5. AIMS/OUTCOMES

MAJOR AIMS:

To use Hooke's Law, from lab, for discussion of some views of Law in science. (This continues in Ch. 7, (p.131); Ch. 8, (pp.141,144,149); Ch. 18, (p.269); . Ch. 19, (p.272); Ch. 22, (p.314); Ch. 24, (pp.342-349); Ch. 44, (p.758)).

To have students work through a set of Galilean thought-experiments.

To contrast "volume effects and "surface effects" for samples of different sizes. (This appears in No. 3 of typed problems. I refer to it as "elephants' legs" whenever that kind of discussion occurs again; e.g., in: surface tension (p. 92), comets' tails (p. 131), Joule's accurate calorimetry (p. 437), and critical size for chain-reactions.) Another example: heating buildings of various sizes.

MINOR AIMS:

To provide commentary on elasticity to follow an open expt. on springs in lab. (Ch. 4, Expt. B.)

To show how we sometimes reduce measurements to quantities independent of shape or size of samples used, (e.g., density, field-strength; stress, strain, moduli).

5. NOTES

Assign chapter for reading and assign the typed problems. In lecture, do nothing, or at most demonstrate the examples sketched on page 79. A short piece of thick-walled rubber tube, given to each student to mark with ink, will provide laboratory-demonstrations of the deformations sketched on pages 85 and 86.

In class, we mention the importance of the "elephants' legs" discussion in other parts of science. But we explain that the calculation for animals is often misleading, because great change of size often shifts the design-problem to a different matter, e.g., temperature-maintenance instead of bone-strength. We give "independent of ..." as a useful wording for answer to No. 4, and emphasize the importance of such a statement.

5. PROBLEMS

IMPORTANT: typed problems on pp. 82-84.

Chapter 6. SURFACE TENSION

(An optional topic, offered chiefly for the delight of some experiments. However, it provides an important estimate of molecule-size by macroscopic measurements. Unless you are interested, omit the chapter or reduce it to the oil-molecule-measurement, (pp. 102-104).)

6. AIMS/OUTCOMES

MAJOR AIMS:

Students know one way of measuring molecule size. (Measurement, in contrast with assertion, seems to me essential in teaching atomic physics. For this, students must see a measurement,* then do Prob. 5 and preferably 6+7 too.)

MINOR AIMS:

Practice in making inferences (Prob. 2).

Introduction to molecular pictures of solids, liquids, gasses (Fig. 6-4).

Contrast of "surface effects" and "volume effects."

Idea of long-range, short range... forces.

6. NOTES

If this chapter is not studied, students should at least look at Fig. 6-4 (p. 89) as preparation for later topics.

*Demonstration: Collect a tiny drop of olive oil on a very thin wire. Put this in a projection lantern beside an inch scale — transparent photograph — with 1/100 inch graduations and estimate its diameter. Easier if you adjust the drop's diameter to, say 2/100 inch by teasing with an oily wire beforehand. Then transfer the measured drop to clean water dusted with lycopodium and estimate the diameter of the patch to which the oil spreads. Calculate oil molecule length. It is easy to obtain a clean surface by Langmuir's technique: paint a tray, (metal or plastic), with paraffin wax colored black with soot. Fill the tray with water until the water bulges above the rim of the tray. Then use two wax-covered strips of metal as booms to sweep the surface clean from center to ends, leaving very clean water in the center.

6. PROBLEMS

ESSENTIAL:

5 (The result, 16×10^{-10} m., is reasonable for olive oil. The point of part (b) is to make students realise there is a risky assumption in calling that the molecule length).

IMPORTANT:

6+7 (warn: (i) avoid mixing units; use meters and kg.
(ii) see "Note:..." in (a)).

MINOR:

2,4 should be assigned if there are demonstrations. (Figs. 6-19, 20 are drawn so that they fail to give away the answers to Prob. 4. Therefore, after Prob. 4 has been assigned and answered a demonstration of Fig. 6-19 should be exhibited.)

Chapter 7. FORCE AND MOTION

(Traditionally, Newton's Laws form the core of classical physics in an elementary course, a field for much study and many problems. But with so much physics still ahead of us — astronomy, molecules and energy, electricity, atoms and nuclei — it seems shameful to spend long on this chapter and the next, when students do not yet feel the need for them. It seems obvious to us who teach that Newton's Laws untangled the confusion over motion just

when everyone felt the need, and obvious that our students will need to use Newton's Laws in atomic physics as well as astronomy. All that is obvious to us, who are storekeepers of physics; but all that is not obvious to the students who are our customers; and good teachers respect the customers' interests. So Chapters 7 and 8 should be treated quickly, and then the few essentials in them will be re-taught more slowly by later uses. It would probably be best of all to postpone Chapters 7 and 8 until after Chapters 19 or 20, and then give Newton's Laws when astronomy has made the time ripe for them – I tried that one year, and enjoyed it, saving much wear-and-tear and some time as well.
Note that, in the present order, Chapters 7 and 8 can spread some of their problems – and the understanding which we hope the problems promote – over later weeks, on into astronomy.)

7. AIMS/OUTCOMES

GENERAL AIM:

To give working familiarity with $F = ma$, not for solving Atwood's-machine problems but as a guiding principle in astronomy and atomic physics.

ESSENTIAL OUTCOMES:

Sure knowledge of how to use $F = ma$, with absolute units;

Idea of "g" as field strength, of value 9.8 newtons/kg near Earth.

A feeling of familiarity with concept of mass.

Knowledge that weight is a force.

A belief in Newton's Laws as summaries of behavior, based on a mixture of experiment and definition.

(We should not argue long or heavily with our beginning students, but we should say enough to keep them from swinging to either extreme: mechanics deduced from three laws announced by authority; or $F = ma$ laboriously extracted from a carefully-argued but not-quite-logical set of experiments.)

MINOR OUTCOMES:

A general feeling for dynamics as a healthy mixture of experiment, reasoning and imagination.

Distinction between gravitational mass and inertial mass. (I leave this to reading and to class discussion in the faster class divisions. We then ask an examination question that offers an opportunity to show knowledge of this, the two kinds of mass. See Ch. 31, (p. 498) for comments.)

7. NOTES

I show Demonstration I(a), I(b), II(a), II(b), II(c) quite carefully, discussing the arguments and assumptions involved. Also show "wig-wag" of Fig. 7-26. I discuss mass, weight, field strength, absolute units, at considerable length.

Some lecture and class-time then has to be devoted to clearing up assignment problems after students have tried them; but time taken to explain difficult problems all over again several times does not seem to pay. Those students who need a repeated explanation do better if they move to a new problem – the yield of subsequent hammerings is too poor to make good class-teaching. Then, after a rest, such students often come to grasp what seemed the difficult point, of their own accord. Thus we do not use Atwood's machine, but leave the discussion of pages 130-131 for fast students to read on their own. But we do give a demonstration of a giant Atwood machine with a bicycle-wheel at the ceiling, to show a spring scale weighing a sandbag while the system is accelerating. This not only illustrates Prob. 10, but it answers an old dispute, the "vertex" question (Prob. 20 of Ch. 1, (p. 24)).

7. PROBLEMS

(NOTE that in the case of Chapters 7 and 8 we can spread the problems – and the growth of understanding we hope they will promote – over several weeks, on into the period of astronomy lectures, when there are few immediate assignment problems.)

ESSENTIAL:

1 (p. 108) (Whatever students say on behalf of friction, we argue back for demons in class, along the lines of Ch. 24, (pp. 344-345). We leave the discussion unfinished, because we hope students will formulate their own distinction. We do not refer them to Ch. 24, but let that wait until they neet it.)

2+3 (This, which seems to a physicist obvious though sloppy, is a severe test of growing knowledge and a flexible mind. We assign this, and, without giving any answer, re-assign it a second week, and only after that do we help those who fail.)

5 (Test of reading; and provides a needed number.)

6 Assign in a later week. This, and the ensuing discussion will do a lot to clear up ideas about mass (see note*).

(Answers: yes; 0.4 m./sec^2 because...; same, because...; 1.96, because...; same because...; less because.... In grading, we give little credit for the numerical answer, much for the reasoning of "because....")

*NOTE. I have a tradition with colleagues who make examinations with me that, when we have manufactured a question, we consider whether we should add an extra part to the problem, asking, "Would the result be larger, smaller or the same, and why: on the Moon/at center of Earth/in a vacuum/ in freely falling elevator/ under water?" We make some such additions to problems over a wide range, from barometers to calorimetry to alpha-particle scattering.

MEDIUM:

4 (either assign this; or describe in lecture). (See Prob. 20, p. 132.)

7,8 (typewritten) to give practice in successful calculations.
(Note that success with 7 can be tested by exam questions that look quite different; e.g., "a 2 ounce bullet emerges from a rifle, barrel 2 ft. long, with speed 2000 ft/sec; estimate the average force on bullet.")

The answer to 7 (vi) should be expressed in tons-weight. Then I comment on "This is the force that drives up through his feet, ankles, knees,... to stop him. Although it acts for only a short time it will do severe damage." A colleague tried the experiment with straight knees, but with only 3 inches drop instead of 4 ft; and he was sore for days.

9 (one week later than 7,8); a review that prepares for similar problem in Ch. 8.

10 (one week later than 7,8); prepares those who are interested in Relativity, and itself ends with a relativistic question.

15, 16, 21, 22, 23, 34, 35, 36 are all straightforward calculation problems. I assign a few of these in later weeks, to continue the typewritten problems 7-10. We avoid assigning many because that would delay progress and would probably change the flavor of the course.

ESSENTIAL:

13 (Simple example; emphasizes F being Resultant).

14 (A reading test. I find it necessary).

17 (Part (a) asks for myth-&-symbol).

18 (We change to a "newton" version of this for exams).

19 (I use this as a simple example in which common-sense may censor the answer. Forgetting to put F in absolute units advances the child only 2 ft instead of the correct 72 ft; complete confusion between mass and force can speed the child up to 11 miles/hour).

24+25 Important because they show application to atomic physics. (These continue Ch. 2 Prob. 18 and will be used again in Ch. 36, Probs. 2,5. Assign these after some of the simpler problems listed under MEDIUM. When students bring answers that look like an egg-laying competition, ask them to study Ch. 11 and use standard form for large numbers and small in atomic physics.)

26 This seems to be needed. Assign after first week of problems on Ch. 7.

28+29 This proves to be hard and needs both courage from students and encouragement from instructors; but we find it well worth-while. (There is some comment on this in Ch. 31, (p. 497).)

31 (Only necessary if, like Galileo, we appeal to inclined plane as experimental basis. Parts c+d test appreciation of myth-&-symbol.)

MINOR:

20 offer it as options: or keep it for an exam.

27 is a reading test: I use it to promote class discussion.

30 is a trick: the answer is not 64 ft/sec^2.

33 is useful in exams, as a combination of Chs. 2 and 7.

Chapter 8. MOMENTUM

8. AIMS/OUTCOMES

MAJOR OUTCOMES:

A feeling for momentum; and a knowledge of its use in force problems, (needed in particular for Kinetic theory; collision problems (Ch. 26); Newton's discussion of Kepler's Law II (p. 320); nuclear physics).

Conservation of momentum and its universal application.

MINOR OUTCOMES:

First glimpse of potential-hills in collisions, (See Chs. 43,44); and the idea that contact means simply big repulsions.

Mention of neutrino (Important in Ch. 26, (p.407), and Ch. 43).

8. PROBLEMS

(NOTE that in the case of Chapters 7 and 8 we can spread the problems – and the growth of understanding we hope they will promote – over several weeks, on into the period of astronomy lectures, when there are few immediate assignment problems.)

IMPORTANT:

1(a), (b), (c), 5,6,7,8 (all typewritten).

9,10,16,17.

11 (Assign in later week; discuss carefully in class. I usually issue an answer-sheet for this, tracing the momentum of that quantity of air that passes through in, say 7 seconds. I avoid taking standard time of 1 second because the 1 does not remain as a visible factor to be divided out when we divided by Δt to find F.)

27 (Hard. Assign later. Useful for Relativity.)

MEDIUM:

3,4 (Assign only if demonstrations of these are given. Then the problem helps slower students.)

2, (p. 140) is good preparation for atomic physics but it proves puzzling. (Corrections; For a better result give B final speed 1.25 instead of 1.20. Change last line of part (c) to "get is test of addition and conservation of momentum as vector.")

MINOR:

15,18,24,25 make useful exam questions; and 26 makes a fairly hard, orthodox, exam question (See General Prob. 32, (. 764).)

8. NOTES

We need to emphasize in lecture and class our belief that MOMENTUM IS ALWAYS CONSERVED or students will not give it its full value.

Some demonstration like Fig. 8-1 seems essential – but one in which secret losses of momentum by friction have to be explained away may do more damage than good. A multiple flash picture of a collision of pendulum bobs (or of dry-ice pucks) would be probably best of all. With a Polaroid camera the picture can be converted into a lantern slide within minutes of the actual experiment. When the picture is then measured, students will see that momentum is conserved, as a vector.

Null-result experiments like those of Figs. 8-5, 8-6a,b are fun to see but much less convincing as tests of momentum-conservation – they look like little more than a government Mint showing it can count its own coins.

The view that Law III is a statement of our accounting-system rather than something that can be shown by experiment (pp. 144,147-149) is derived from Poincaré's discussion of Newton's Laws. Some of my colleagues bring violent objections to this view to staff-meetings; but their arguments would not convince Poincaré. I welcome such discussions — they help to keep the teaching alive — but I urge all to avoid letting these disagreements expand into class discussion which would confuse students, and delay the course with a philosophical wrangle over a matter that would not have general interest. Newton himself supported his Law III by experiments to show conservation of momentum in pendulum collisions. (See his account for his very clever method of dealing with air-resistance: in Principia, and quoted in Magie's "Source Book in Physics.") Of course, we can derive Law II from momentum-conservation if the latter is vouched for by experiment.

Chapter 9. FLUID FLOW

(This is an optional chapter. "Bernoulli effects" are not mentioned again, except — unnamed — in footnote 6 on page 505. Viscosity is discussed afresh in Chapter 30. Air-friction on a droplet is discussed in Probs.14, 15 of Ch. 33, (p. 566) and used for Millikan's Experiment in Ch. 36. So the only strong reasons for including this chapter are those given below.)

9. AIMS/OUTCOMES

MAJOR:

For delight in seeing Bernoulli-paradox demonstrations and in finding they are examples of $F = ma$.

To continue the campaign against demons (i.e., to show that several apparently different paradoxes can not only be grouped under a single description — Bernoulli's Principle — but can then be explained as cases of familiar behavior, $F = ma$).

To introduce the idea of terminal velocity, (to help prepare for Millikan (Prob. 8, p. 167)).

MINOR:

Students see how streamline motions can be compounded by vector-drawing to make patterns which show solutions of $\nabla^2 v = 0$. Then they will meet the same pattern(s) for electric or magnetic fields.

To produce the "catapult" field pattern (See pp. 164, 575, 615).

To discuss mechanisms of fluid friction to help discussion of viscosity in Ch. 30

9. NOTES

The expt. of Fig. 9-6 is difficult to arrange but a delight to see. If it is shown, the pattern should also be constructed by working through Prob. 6, (p. 164) on blackboard.

The glass tube for the expt. of Fig. 9-15(c) is well worth making. It should be of 3/4" or even 1" bore and have an upward crook for outlet, as in Fig. 9-15(b).

9. PROBLEMS

MEDIUM:

6 needs some care and a warning to use long vectors near source or sink and much shorter ones far away; then the result is worth the trouble.

7 (useful question on mass).

8 (In (c) one might be able to tell by using cigarette smoke; but the fact that the chip reaches a terminal velocity will not tell. The answer to (e) provides a much better test, which can be carried out with the paper trays of Fig. 9-30. They can easily be loaded by placing one or more equal sheets, folded, in them.)

MINOR:

9 (remarkable for wrong answers by pre-medicals. Streamlines will leave a thick stagnant layer just where it is not wanted. Even turbulence is poor).

17 and 18 are useful tests of reading and comprehension.

Chapter 10. S. H. M. AND WAVES

(In my own course this chapter is skimped, treated by occasional contacts. It provides reading to follow the pendulum investigation in lab; also reading to go with demonstrations of interference, etc., late in the course — interference is given little attention here and has to wait till waves and photons are treated in Chapter 44.

My advice to anyone planning his course would be to consider carefully how much description of wave-motion and spectra he will need for his treatment of Ch. 44, and then make his own choice of treatment for this chapter — and manufacture his own problems — all at the expense of economies in such chapters as 6,9,33,34, and parts of 7 and 8.

10. AIMS/OUTCOMES

MAJOR:

Provide a discussion of S. H. M. to follow pendulum labs. (In the last week of pendulum labs, we give a 20-minute demonstration lecture on S. H. M., with expts. of Figs. 10-3,5,6,7,8,9,10, and an oscilloscope with AC.)

Offer an example of a (difficult) theoretical argument (Prob. 1).

Provide acquaintance with the following, all needed for Ch. 44:

Young's fringes, for water ripples and for light; diffraction.
Diffraction-grating and spectra, Electromagnetic spectrum,
Line spectra (more in Ch. 44), X-ray spectra,
Standing waves.

10. NOTES

The derivation of speed of waves along a rope, at the end of the chapter, does not seem to be a normal or necessary ingredient of this course. It is inserted because a derivation of the speed of electromagnetic waves is modelled on it (see Ch. 37, p. 622).

10. PROBLEMS

IMPORTANT:

1 (typewritten). After all students in a lab group have arrived at the (approximately) isochronous property of pendulums, we run through on the blackboard the argument sketched in this problem, parts (i)-(v), without disclosing the conclusion. Then we issue copies of this problem, to be completed by next lab. At next lab we show examples of S. H. M. and offer springs for a quick test.

Chapter 11. ARITHMETIC

(This is a reference chapter: a mixture of topics for students who need help. I assign it for reading, assign most of the problems, and expect some benefits (see below) but do not treat it in lecture, except for a strong appeal for "judging" with an example of its use.)

11. AIMS/OUTCOMES

MAJOR:

To provide explanation and practice in expressing big numbers and small in "standard form".

To cure some troubles over percentage errors.

to discuss proportionality and use of graphs.

To discuss the value of rough estimates in some parts of science ("judging").

To give a scheme for quick approximate arithmetic ($2^n \times 10^m$).

11. NOTES

We discuss percentage errors and differences again and again in lab, (not as a routine demand for a tedious, pious estimate, "Discuss the probable errors of your experiment," but as a good method of comparison, as in "Show the disagreement between your calculated value and your measured value as a %").

Arithmetical judging should be studied at latest when the need for it arises in astronomy (Ch. 22). After that, a stronger need will arise in atomic physics. The scheme suggested, powers of 10 and powers of 2, looks clumsy but students find it easy to learn, and it works reasonably.

Linear relationships and graphs arise in Ch. 1 and in early labs. Page 201 should be read after the matter of a "question-asking line" has been discussed in lab for an experiment such as the rolling wheel, Expt. C in Ch. 4.

11. PROBLEMS

IMPORTANT:

1,2,3,4,5 (which is answered in the question), are part of reading the text on % errors.

6 is a test of that reading.

4 will be used in Ch. 30 in problem on uranium separation, page 446. See also footnote 2 of Ch. 22.

8+9: assign as soon as standard form is taught or assigned for reading — no need to wait until K. E. is discussed in Ch. 26.

MEDIUM:

10 is useful if pendulum expt. is done.

7,12,13 are routine test questions.

PART TWO. ASTRONOMY

AIMS/OUTCOMES

MAJOR:

A sense of understanding theory, from seeing good theory develop in one part of physical science.

MINOR:

An example of Newton's Laws of motion put to use, as preparation for other (more risky) uses in molecular and atomic physics.

A delight in astronomy, as a piece of science whose growth is easily understood.

With the major aim in view, we must give some attention to the simple information and description of early empirical stages in the first two chapters (12,13). A mature reader, taking these chapters as introduction will find a single reading is sufficient; but students busy with several courses need more than that casual reading if they are to profit from the Newtonian synthesis. So in practice I devote a lecture to each of these chapters — and sometimes spend even longer over the information, with a small model planetarium. Then I take time and care over Greek theories. Afterwards, I regret the time taken; but I know I should regret still more having to exhibit the work of Copernicus, Kepler and Newton against a background of ignorance of both earlier information and earlier theory.

Then the chapters on Copernicus, Tycho, Kepler, and Galileo should go quickly. A chapter on circular motion provides a necessary tool, and we are ready for a careful study of Newton's work, building the grand picture it deserves. This second part should end with thorough treatment, not just cheerful description. All through, the growth of thought should rank with the growth of astronomical knowledge.

REFERENCES for teachers in this field of astronomy.

The books suggested below are useful for further reading. The first two are the most likely to be useful.

Lancelot Hogben, "Science for the Citizen." (The early chapters contain a good, simple account, for laymen, of the celestial sphere and its coordinates, celestial measurements and navigation.)

J. L. E. Dreyer, "History of Astronomy from Thales to Kepler." (A very good account of Greek astronomers and their theories, written by a professional astronomer who is also recognized as an historian. The book continues the story in detail on through Kepler and ends with a less detailed chapter on Galileo.) (Dover)

V. G. Childe, "Man Makes Himself." (A very fine account of early civilization by an archeologist, who gives the layman an excellent picture of scientific work in his field.) (paperback)

O. Neugebauer, "The Exact Sciences in Antiquity" gives an account of Babylonian astronomy.

PTOLEMY: Printed versions of the Almagest are now available with parallel texts in Greek and French (by Halma) and in Greek and English. But, except for seeing the great wealth of Ptolemy's work, the general reader will gain more from Dreyer.

COPERNICUS: A. Koyré, Copernicus (in French) (Biographical comments; and parallel Latin and French versions of Book I, "Des Révolutions des Orbes Célestes").

TYCHO BRAHE: J. L. E. Dreyer, "Tycho Brahe" is the standard biography.

KEPLER: Kepler's collected works, (mostly in Latin), have been published in 8 volumes: ed. Frisch, Frankfurt – 1858-71. A new collected edition is being published. There is a good biography by Max Casper, translated by Hellman (Abelard-Schumann).

A. Koestler, "The Watershed" – (Doubleday paperback) taken from the author's larger book, "The Sleepwalkers." This is a biographical account of Kepler's life and work, with some comments on Tycho and Galileo. Critics differ on this book: it is written with skill and considerable knowledge of the original texts but some of the views are debatable.

GALILEO: There is a good biographical introduction by Giorgio de Santillana at the beginning of his translation of Galileo's Dialogue (Univ. of Chicago Press. 1953). From time to time articles in journals and books on the History of Science tell us about things that Galileo did not do and make us suspect that some of the earlier biographers were unreliable.

Déslambres, "Astronomie" (A four volume historical account, well written, by a French astronomer, about 1820. The author works through some of Kepler's arguments and calculations in considerable detail but neither this French version nor Kepler's Latin makes easy reading.)

NEWTON: One of the best biographies is that by E. N. da C. Andrade.

FOR GENERAL READING IN HISTORY OF SCIENCE:

Sir Willaim Dampier, "History of Science and Philosophy" (A great book in fine English by a physicist who lived and wrote among scientists and historians. The text edition ($3.75) is now easily available from Cambridge University Press, N. Y.) This is a book for every teacher to keep at hand beside his dictionaries.

H. Butterfield, "The Origins of Modern Science from 1300 to 1800," (Macmillan, N. Y., 1957). (A historian's lectures to scientists, on the history of science. They give welcome insight both into the methods of historians and into sound history of science.

A. R. Hall, "The Scientific Revolution" (Beacon Press, 1956). (An interesting account and commentary by a good historian of science.)

I. B. Cohen, "The Birth of the New Physics" (Doubleday paperback). (A good account by a leading historian of science.)

NOTE: Many of the remarks on history of science in texts written by sound scientists are the product of a tradition of unreliable myth and well-meaning careless guessing, rather than of proper historical study. Historians of science urge us to be careful.

Chapter 12 and 13: MANKIND AND THE HEAVENS: FACTS AND EARLY PROGRESS

12-13. ESSENTIAL AIMS AND OUTCOMES

A general feeling for the way in which astronomy may have emerged from empirical knowledge that was necessary to developing man.

Some factual knowledge: the constant pattern of the stars; the motions of star pattern, Sun, Moon, Planets.

12-13. NOTES

Students need two pieces of explanation, at the outset:

(i) What the problem was: What were the heavenly motions to be accounted for, and why were accounts of them important?

(ii) That we are going to start with ancient views, so that we can trace the development of knowledge as an example of theory. Unless we say clearly "This is not what you now know to be true" we are apt to meet confusion and objections. (We owe it to pre-medicals particularly to point out the importance of this part of the course, as preparation for studies of theory in modern medicine.)

For our purposes, students must know that planets are seen to move in epicycloid patterns through the star pattern, and that the Sun and Moon also move along paths through the pattern. It is not essential to know that all those paths are close together — in the zodiac-band that contains the ecliptic. It is not essential for them to know what the ecliptic is (to slower students, as to our ancestors, the separating out of effect of daily spin from the other motions is a difficult step).

If you are trying to decide how much of these two chapters must be taught, try the following: (a) Read chapters 14,16,17 on Greeks, Copernicus and Kepler, and decide on minimum needs of preparation: then (b) talk with some students about astronomy and find what they already know. The usual effect of (b) in our urban civilization is to increase our estimate for (a).

The time-spans given for early man etc., are very rough: they may well be wrong by a factor of 2 either way.

In talking about primitive man and astronomy, I try to give a sense of necessity — the uses of astronomical knowledge ranking with those of arithmetic and geometry — and a sense of wonder — an emotional delight not only in the knowledge but in early man's skill in extracting it.

Some kind of simple planetarium is a great help in illustrating the motions of Sun and stars; but that takes considerable time to show. When we have reached Tycho and Kepler we doubt whether the time spent on the planetarium was worth-while. A model to show a planet's epicycloid motion through the star pattern is well worth having. In discussing the Copernican system I use a model of Sun and Earth and Jupiter, with gears to produce motions of Earth and Jupiter around the Sun; and a flashlight tied to the Earth-Jupiter sight-line, to make a spot of light on the ceiling. At this earlier stage I use the same model (without explanation) to show epicycloid motion of "Jupiter" (flashlight spot) on the ceiling. (For zodiac, etc., some of the pictures in the children's book "The Stars" by H. A. Rey are a great help.)

13. PROBLEMS

IMPORTANT:

3 makes sure that students have some knowledge they need for Greeks and Copernicus.

5 is not essential but it raises the important question of longitude measurement. (Donne's comment was serious. This need for an accurate timekeeper grew and grew. Galileo proposed to use eclipses of Jupiter's moons as the universal time-markers. In 1714, the British government offered a prize of £20,000 which was finally won by Harrison's fourth clock.)

MEDIUM:

1,2,4 give questions and reminders to students who are not familiar with seasons, eclipses, etc., from General Science courses.

Chapter 14. GREEK ASTRONOMY

(This is an important chapter; but it is easy to spend too long going into details. Yet, if it is just left to reading, students will probably fail to grasp the importance of Greek theory or its success; so it needs one or two lectures emphasizing its highlights.)

14. AIMS/OUTCOMES

ESSENTIAL AIMS:

To give a feeling for the Greek form of theory as a machine or rational scheme.

To establish a geocentric "machine" as able to "save the phenomena" (see Notes).

IMPORTANT AIMS:

To show several Greek schemes as a prelude to Ptolemy's, (needed for discussions of theory in Chapters 22,24,...44). As a minimum I suggest:

Pythagorean scheme of simple spheres,
Eudoxus' scheme (see Dreyer for further details),
Aristarchus' scheme (needed for Copernicus).

To show Ptolemy's scheme as a complicated, successful machine. (This needs a short description of the simple epicyclic scheme first. Then we can draw Ptolemy's arrangement for Sun and several planets. If at the end, students have a headache, I am satisfied.

To mention Hipparchus' discovery of precession (in preparation for Copernicus' simpler description and Newton's explanation).

To show how early measurements of celestial distances were made.

14. NOTES

Strictly speaking, "to save the phenomena" meant to fit the facts rather than to give reasons for them.

It is not essential to describe Ptolemy's system in full detail, with its equants and essential constancies; but I think it is better to do so, so that students see the lengths to which Ptolemy went to make a successful scheme. I mark the Earth on a large sheet of transparent plastic, and draw an eccentric circle for the Sun's orbit, with an equant. Then I hang another sheet of plastic in front of the first, showing a planet's main circle and epicycle, with EQ of different size and direction; then another plastic sheet with another planet's machinery. These sheets are hung in front of each other, on pegs, with the Earth in the same position on all. With a backing of tracing cloth lighted from behind, the combined picture shows (part of) the Ptolemaic scheme, as in Fig. 14-27. (Note: in that Fig., the epicycle radii to P and P' ought to be parallel to the Earth-Sun direction E-S.)

In discussing use of eclipses for Moon's distance measurement, I have a huge scale drawing of Fig. 14-19(b) right across the lecture room wall. That makes it easier to point to the geometry and carry the argument through. (It also explains, by showing actual proportions, why eclipses are rare.)

Models of Figs. 14-14 and 14-18, with globes for E. S. M. and elastic threads to represent rays of light, make the measurements easier to understand. The right angle of Fig. 14-18 is not obvious to some students until they see a model.

In describing precession from the Ptolemaic viewpoint, I grip my own belt, with a hand above each hip, and tug it around circumferentially through the belt loops of my pants, saying "the zodiac belt slips slowly around like this, carrying the celestial sphere and all the star patterns with it, while the Earth and equator stay fixed."

In general, I make a strong contrast between all the Greek schemes, and mystical superstitions or the empirical graphs of Babylonian astronomers. I praise Eudoxus highly and Ptolemy very highly for successful machinery.

14. PROBLEMS

IMPORTANT:

1 is a pure reading-test; but without it this early material is likely to be skimmed too lightly. The details of these methods are not needed for later studies; but we do need to emphasize early real measurements. As in atomic physics, we have to take positive steps to avoid essential data "appearing from nowhere," just handed out by a book.

Chapter 15. AWAKENING QUESTIONS

(This is a short chapter just for reading; half of it notes for succeeding chapters. Roger Bacon, Leonardo, Alphonso: each deserves a mention. For Leonardo, see Dampier "History of Science;" also see pp. 287,315. The long traditional teaching of Ptolemaic system needs emphasizing.)

Chapter 16. COPERNICUS

16. AIMS/OUTCOMES

ESSENTIAL OUTCOMES:

Knowledge of: the Copernican scheme, Copernicus' reasons for preferring it; the measurements and explanations that the scheme provided.

How the theory brought with it new knowledge – in terms of the theory – of the relative distances of planets, which had been indeterminate in Ptolemy's scheme.

How the theory explained some known facts, such as changes in brightness of Mars, and simplified some others, such as precession.

16. NOTES

There would be little point in just describing the Copernican solar system – students have heard about it in Elementary School. Our account should show clearly how Copernicus accounted for the apparent motions of planets (e.g., Jupiter). For this I use a mechanical model, with gears and a beam of light as Earth-Jupiter pointer to the stars. Failing that, I use one of my hands as Sun; the other, holding a long pole, as Earth moving around Sun; then I have the pole pass through a ring held by a student whose hand represents Jupiter moving more slowly around the Sun. The pole then points to Jupiter's apparent position in the stars on the walls and ceiling of the room.

I illustrate the new view of precession with a toy globe, in preparation for Newton.

For orbit-estimate for outer planets, see Hogben's "Science for the Citizen."

Purists insist that the Copernican scheme was not simple. To represent the observed facts, small epicycles had to be added until the scheme had many circles, though not as many as Ptolemy's. But these extra circles played small correcting parts; so, to the general reader, as to Copernicus, they do not spoil the essential simplicity – whereas Ptolemy's small circles played a major part, producing the obvious loops in planetary paths.

16. PROBLEMS

IMPORTANT:

1,2 are much more profitable than they look: they serve to promote reading and review. They are not essestial, but some students gain perspective from them.

3 is a reading test. (If students leave the argument of (a) unfinished, saying "then trigonometrical computations yield the ratio," I make fun of that pompous evasion and ask for the detailed clear statement that the ratio is the sine of a certain angle, which is measured directly – and the sine can be got from drawing or tables.)

4 is a reading test. It is essential unless this knowledge is to be left vague, to emerge in very disappointing form in any exam that asks for it.

5 (insist on diagrams). The answer to 5(b) calls for some thinking and a sketch.

Chapter 17. TYCHO BRAHE

17. AIMS/OUTCOMES

ESSENTIAL AIMS:

To describe the gathering of accurate, systematic data that were essential later on.

MINOR AIMS:

To show Tycho's good use of techniques: well-constructed instruments with tables of errors; long series of observations.

17. PROBLEMS

IMPORTANT:

1 (The answer, about 1/40 inch, throws some light on Tycho. The method is useful for Prob 3).

3 (a, to-and-fro, SHM; small circles. b. about 4×10^{12}; angle 1/6 as big).

4 (is simply reading test: disappointing unless a model was shown and used in lecture). As used, it gives angle with horizontal.

Chapter 18. KEPLER

18. AIMS/OUTCOMES

MAJOR AIMS:

To show some forms of theory.

To provide knowledge of Kepler's Laws (for Ch. 22).

18. NOTES

Kepler's "Law Zero" provides an interesting example for discussion, or for exam question. (See criteria (a) and (b) on p. 269).

The construction of Fig. 18-5 deserves to be explained carefully in lecture.

Law II answers the need for "something constant" in the motion around the orbit, to replace Ptolemy's constant arm-rotation around equant-point. See Fig. 14-26.

I show a lantern slide of the Law III table (p.268) covering up the right hand half at first then showing 4th column, then 5th, then 6th. I usually read aloud Kepler's remarks on pages 267, 269.

18. PROBLEMS

IMPORTANT:

2 (plain bookwork, but seems to be essential review).

3 (is a good puzzle for able students, and its answer will be used in Ch. 40, (pp. 652,653). Slower students need two warnings:

(i) "Do not spend hours on this; but try for short periods and let it simmer."

(ii) "I hope no one will be so stupid as to think there is any value in getting the answer from someone else."

MINOR:

1 is pure bookwork, of little value unless expanded into a question that asks why Law 0 is not regarded as "good science."

Chapter 19. GALILEO

19. AIMS/OUTCOMES

ESSENTIAL OUTCOMES:

Knowledge of Galileo's contributions to astronomy with his telescope.

Knowledge of the foundations Galileo provided, by his writings and arguments, for Newton's Laws.

IMPORTANT OUTCOMES:

Understanding Galileo's change of science towards mathematical formulation.

Delight in Galileo's teaching.

19. NOTES

It is easy to spend too much time on Galileo's biography — yet this is a chance to return to Mechanics and discuss his contribution: the idea of codifying experimental knowledge by mathematical ideas.

If telescopes have not been brought out earlier to look at the Moon and planets, now is the time. Telescope parties are well worth the trouble. A very good calendar for locating planets — one that a non-astronomer can understand easily — is published by Maryland Academy of Sciences, Baltimore, Maryland, about 25 cents each year.

Chapter 20. THE SEVENTEENTH CENTURY (A chapter for students to read on their own.)

20. AIMS/OUTCOMES

IMPORTANT OUTCOMES:

Science becoming public, respectable.

Descartes' contribution of graphs.

MINOR OUTCOME:

A discussion of the logic of the graph in early lab on rolling wheel (Expt.B Ch.4)

Chapter 21. CIRCULAR MOTION (This chapter is essential now.)

21. AIMS/OUTCOMES

ESSENTIAL OUTCOMES:

Know that motion in circle needs inward force, provided by real agents.

Know that the needed inward force is mv^2/R.

IMPORTANT OUTCOME:

Ability to derive $a = v^2/R$, if only to make mathematics seem reasonable.

21. NOTES

This chapter provides the essential derivation to be used for planetary motion, cyclotron, mass spectrograph, electron streams in lab. I discuss examples, insisting that the motion does not provide the force but needs it, so that the force must be produced by strings, rails, gravity, etc. Show loop-the-loop and discuss real forces on car at various places. Derive $a = v^2/R$ in lecture: instructors repeat that in class; then assign derivation as a problem; then offer again in lecture.

The chapter looks bulky and one is tempted to spend much time on it. That does not pay. Class discussion when problems have been tried is very valuable, and uses in Newtonian theory will help, but extra lectures on groundwork are wasteful.

21. PROBLEMS

ESSENTIAL: Preliminary problem 1 (assign a week or more before).

2 (assign at very beginning of treatment).

3 (assign with or after Prob. 2).

4 (assign after derivation has been done in lecture and repeated in class).
5
6,8

MEDIUM: (10 ? for pre-medicals. In (e), 10^6 combined with chemical analysis gives number of atoms of C,H,O, etc., in one molecule; centrifuging gives absolute "diameter" of one molecule: thence, a rough indication of size of a single atom, from a macroscopic measurement. Another macroscopic measurement that has succeeded: fold a large, counted, number of monolayers on to a glass plate by dipping in water covered with monolayer; strip off the resulting, visible film; fold it many times and measure with micrometer.)

Note that there are problems involving v^2/R at ends of Chapters 22,23.

Chapter 22. NEWTON

(Chapters 22 and 23 form the essence of PART TWO; and Chapter 24 is a commentary on the essence. This is material to teach thoroughly, taking time to convey understanding and delight.)

22. AIMS/OUTCOMES

ESSENTIAL OUTCOME:

An understanding and appreciation of Newton's gravitational theory. (This should be a working understanding, not a vague wondering gaze from afar. Each student should be able to do some of the derivations and be familiar with the general idea of the others.

22. NOTES

This chapter deserves two weeks or even more. Before starting this chapter, cover Ch. 21 — or at least begin circular motion and let it run on beside the beginning of Ch. 22.

As soon as this chapter is started, have students work through Prob. 1. The idea of inverse-square gravitation needs careful explaining. It is so familiar a name to students that we do not realize that its meaning is quite strange to them.

I go through derivations of Kepler III and Kepler II in detail: I point out that Kepler's Laws were the talk of the town, waiting to be explained; then I go through the derivations of Kepler's Laws III and II — and then ask for their derivations in next problem assignment. I apoligize for lack of a non-calculus derivation of Kepler's Law I, but I state the assumptions and say "It is only a matter of mathematical machinery, from inverse- square to ellipse." Then I discuss the other achievements, trying to build a structure of linked knowledge, with a feeling of surprise and delight. The only topic I play down is angular momentum, which would take a lot more time for reasonable treatment. However, I show turntable experiments to illustrate Kepler's Law II; and I show gyroscopes and give the explanation of Fig. 22-22. The expt. of Fig. 22-20 makes it much easier to see the explanation of precession — it is easily made from a small standard demonstration gyroscope and a wire frame.

In building up a feeling for the richness and extent of Newtonian theory, I find it useful to have a tall historical chart. This is an endless loop of paper on rollers, hanging from ceiling to floor — with items of knowledge (in one color), schemes and theories (in another color), and attitudes such as fear, wonder, (in another) — running from primitive man to Newton, then on through all the achievements of Newtonian theory. Then, when we come to Ch. 22, I work my way down this chart commenting on growth and changes; and I use the later items to prompt me as I build up Newton's full tale. My chart is too big and clumsy to reproduce — I am not sorry, because it is the kind of chart that each one should make for himself. (When students start to copy it, I urge them not to do so but to make their own version if they like.)

I use the discovery of Neptune as a final example.

22. PROBLEMS

ESSENTIAL: 1, as soon as study of Ch. 22 starts, or just before.
2,3 essential review of book work.
IMPORTANT: 4 (but make sure students use short arithmetic); 5(a) or 5(c).

PROBLEMS AT END OF CHAPTER 23 (belong with Ch. 22).
IMPORTANT: Chapter 23, Prob. 1,4.

Chapter 23. GRAVITATION

23. AIMS/OUTCOMES

IMPORTANT AIM:
To show terrestrial evidence for universal gravitation.
To describe Cavendish experiment.

23. NOTE

This is really part of Ch. 22. I assign it for reading: show (and comment on) a lantern slide of the table of expts. on G; and I usually set up a simple form of Cavendish balance and make a rough estimate of G by Pohl's method. (Start with system at rest; measure initial acceleration when large balls are moved in. This avoids need to know torsion constant.)

23. PROBLEMS See end of notes on Ch. 23.

Chapter 24. THEORY

(This is an extra chapter for students to read on their own.)

24. NOTES

This chapter should not be regarded as conclusive. There will be further discussion of theory, particularly in Chapters 34,35.

The story of the plogglies is useful. I tell it in lecture at some stage when an ad hoc theory is looming.

The "vocabulary" offered may do more harm than good. Students should treat it lightly.

The discussion of demons is intended to finish the discussion started with Prob. 1 in Ch. 7. I use it to encourage students to see for themselves the aim of theoretical physics: rational, economical explanation.

Chapter 25. KINETIC THEORY OF GASES

25. AIMS/OUTCOMES

ESSENTIAL AIMS:
Show a simple mathematical theory of gas behavior being developed and use it to estimate molecular speeds.
Give acquaintance with molecular picture of gases (and solids and liquids).
MEDIUM AIM:
Show that derivation of $PV = 1/3....$is a rational, understandable business.
MINOR AIMS:
Have students calculate speed of air molecules and remember result.
Start discussion of separation of uranium isotopes.
Demonstrations of diffusion.

25. NOTES

Much of the value of this chapter lies in its preparation for Ch. 30. There is some value in the derivation, particularly if students develop it for themselves — which is what the typewritten problems are meant for — but not if our only use of it is for a fuzzy prediction of Boyle's Law. (To predict that from simple theory, we must make an additional assumption regarding the meaning of constant temperature, and that makes the story look weak.) We must continue to a measurement of molecular speeds; and we should show diffusion; and promise more in Ch. 30. Boyle's Law must be demonstrated, if not already seen in lab. If barometer has not been used in lab, we must show it and compute atmospheric pressure now. (See Fig. 4-10, p. 71 for trick of getting barometer free of air bubbles by running big bubble slowly up and down.)

In the derivation, avoid starting with t = 1 sec. Then t gets lost and Δ(mv) suddenly turns into force, leaving students confused. The smoothing out of impacts (Fig. 25-6) needs explaining: it is unfamiliar. The key phrase is "big mass." If possible, give a demonstration of a shower of particles hitting a massive anvil.

The estimating of speeds needs both a good demonstration (barometer and density measurement) and strong advertisement of its outcome. Then we must at least mention a direct check (Zartman). I find it helps to show a rough model of Zartman's expt. with lead balls and a rotating bucket. Show Brownian motion, (exhibit in lab?) at all costs.

The diffusion demonstrations (Figs. 25-13, a,b, do more good than one would expect. The bromine diffusion is well worth the trouble.)

25. PROBLEMS

ESSENTIAL: 1 (assign early, before lectures start on this chapter).

2 (a week after Prob. 1), 4 (need to remember answer).

IMPORTANT: 3 (but this has the defect that it makes the tiny effect on pressure of shortened travel-distance seem important and get confused with big effect of molecule-size on MFP. Warn students the former is trivial).

5 (this and Probs. 8,10 are to promote rough guesses).

6 (offers an interesting hope of estimating mass of a molecule. Discuss in class: suppose we could measure speeds of several ash-specks of known mass; then plot speed against mass; extrapolate; read off mass corresponding to the known speed of air molecule. However: we observe only macro-motions, the micro-motions piled up, so we need help of statistician; see Ch. 30).

11 (or Ch. 30, Prob. 3) (Warn students: remember to include mass of 6 fluorines).

13,14 (assign later). These are good preparation for Ch. 30.

MEDIUM: 7,8,10.

Chapter 26. ENERGY

(When new members join the teaching staff at the beginning of the course, I suggest they should read PART ONE at once, and Chapters 26 and 29.)

26. AIMS/OUTCOMES

ESSENTIAL AIMS:

Give a strong set of ideas about energy:

- something important, from fuel, costs money
- something that does useful jobs (in transferring from one form to another)
- something that appears in several interchangeable forms, whose interchanges can be measured by work Fs.
- something with complete overall conservation (for this, continue through Chapters 27,28,29).

MEDIUM AIMS:

Show that K. E. = $\frac{1}{2}mv^2$.

State that energy E has mass E/c^2.

MINOR AIMS:

Give names to energy-forms.

Skill in using energy-conservation for problem solving.

26. NOTES

If, like one reviewer, you only find energy loosely described (as it is at the beginning of the chapter) and do not think the great principle of conservation is set forth fully enough, please read on through this chapter and Chapter 29. The rambling approach and the repeated attacks of guerilla warfare against basing conservation on assertion are intentional. Students come from earlier science courses with statements about energy for which they have never seen any justification; and then propose to use it as a panacea. If Conservation of Energy is a great Principle on a firm foundation — as I am sure it is — it can stand honest discussion and inquiry. I hope students will make a fresh start on ideas of energy, but will emerge with a full belief in conservation, and a sensible knowledge of its basis.

I find that coining the separate name "perpetual movement" helps to get rid of a silly muddle over perpetual motion. (p. 381; and Prob 12, p. 409) The answer to Fig. 26-24(b) is: "Imagine a vertical rod protruding through a frictionless hole in the bottom of a bucket of water. Archimedes' Principle does not apply to that rod." In the chain of Cartesian divers, we can remove the trouble due to thermal changes in the air by replacing it with small springs in the cylinders. The paradox remains; and the explanation lies in the transfer of water from bottom to top every time the chain carries over one bucket.

The personal expt. on p. 383 (also on p. 126) is more successful than it sounds; try it with a lecture audience, asking them to shut their eyes and raise and lower a heavy book while you give the hypnotic instructions.

In starting to discuss conservation, I go through example D, page 400 and discuss its moral.

I derive the expression for K. E. carefully in lecture, first going through the derivation of $v^2 = v_0^2 + 2as$ (p. 28).

The discussion of $E = mc^2$ is primitive and unsound, but some discussion must come now — otherwise it appears much later as a queer modification instead of an essestial property.

Since Chapters 27 and 28 are chiefly for lab, we can go straight on from this energy chapter to Conservation in Ch. 29, with only a short interruption to discuss heat and gas-thermometers.

26. PROBLEMS

ESSENTIAL: 6 for discussion of K. E. + P. E.

IMPORTANT: 1,2,4,5 (necessary bookwork), 7,8+9,11,12,
19,20,22 (these, later; will be needed in Ch. 43),
23+24 (later or much later. Then discuss in class).

MEDIUM: 10,13,14,15,16,17,18,
21 (If cancel Q, we assume Q is not zero — we assume there was something to hit. If cancel w, we have alternative solution w = 0 and v' is the same as v, unaltered. The interpretation is that..., and both momentum and K. E. are conserved in that "event!")

Chapter 27. HEAT AND TEMPERATURE

(This is intended as a guide for a few lab expts. to introduce the idea of heat as mass-of-water x temperature-rise, for use in Ch. 29 on Joule's work. If it is expanded into lectures on heat and temperature, it will waste time.)

27. AIMS/OUTCOMES

MAJOR AIM:

Give idea of heat measured by $M_{water} \cdot \Delta$(temperature), to prepare for Joule's work in Ch. 29.

Discuss idea of temperature as man-made concept, with operational definition.

MINOR AIM:

To tell the Zanzibar story, for other uses.

27. NOTES

I use this chapter in lab, where I demonstrate Expt. B and ask students to do A, C, and sometimes E; and I ask students to memorize informal definitions of temperature and of heat and a rule for measuring heat. In lecture I comment on thermometers; tell Zanzibar story; show and calibrate gas-thermometer (helium); (later I use it to measure temp. of liquid air).

Before feeling too unhappy about this discussion of temperature, see page 451.

Some students suggest that scale of temperature could be made by giving equal chunks of energy to 1 kg of water, starting at various temperatures. This does define a (different) scale, by a rule that then says specific heat of water is constant.

27. PROBLEMS

MINOR: 5 (for vii: low β means small fraction of liquid in tube compared with bulb, therefore small exposed-stem correction. For viii: changes due to pressure when thermometer is inverted).

Chapter 28. POWER (Laboratory Chapter)

28. AIMS/OUTCOMES

MAJOR AIM:

Provide simple power expts., which relate to students' life.

MINOR AIMS:

Continue discussion of food and energy from Ch. 26.

Band-brake prepares for measurement of "J" (Ch. 29, Expt. B).

Use of Ⓥ and Ⓐ in electric measurements points out the need for them, looking ahead to Ch. 32.

28. NOTES

In lecture I have student climb rope and I calculate the energy interchange. Next week, he climbs again, this time with clock, and we calculate his power.

28. PROBLEMS

IMPORTANT: 9, 11,
MEDIUM: 10.

Chapter 29. JOULE AND CONSERVATION OF ENERGY

(A very important chapter of evidence — with the conclusion more or less left to the reader to draw.)

29. AIMS/OUTCOMES

MAJOR AIM: To show and discuss some evidence for Conservation of Energy.
MINOR AIM: To convince students it is safe to take all heat as worth 4200 joules/Cal.

29. NOTES

Sometimes I even begin a lecture with "The Court will sit...." A detailed, appreciative going-through of the Table of results is well worth-while. Before that, I show a tall poster of sketches of experiments (Fig. 29-1) and describe some of Joule's expts. and Hirn's and Rowland's. It is necessary to draw the moral — the court must be asked to consider its verdict — more strongly than the text suggests.

For Lab. (Expt. B) we use the McLeod-Werbrouck water brake with continuous flow. (See Amer. Jour. of Physics, Vol. 28, No. 9, Dec. 1960.) It works well, but we have to explain the torque calculation in detail. For practice with continuous flow, we measure thermal conductivity of a metal rod — steam-heated one end, water-cooled the other — in a previous lab.

29. PROBLEMS

MEDIUM: 1, 2.

Chapter 30. KINETIC THEORY CONTINUED

(A chapter to show how kinetic theory bears fruit. How much we do must depend on students and time.)

30. AIMS/OUTCOMES

ESSENTIAL AIMS:

To show how we extend our knowledge of gases to size, mass, etc., of single molecules.

To point out that our ordinary measurements of gases are statistical averages.

MEDIUM AIMS:

To use a study of gas-viscosity as example of theory and experiment combining to yield further knowledge.

MINOR AIMS:

To introduce idea of quanta through specific heats.

Delight in demonstrations with liquid air, critical temperature, triple point.

Discuss evaporation, boiling.

Introduce idea of ions in a gas; ionization by collision; effect of pressure changes. These can wait; but an early start here is better.

30. NOTES

The early problems use the idea of equipartition; so I describe it as soon as possible, starting it is result of statistics for elastic collisions; and I illustrate it with marbles in an agitated glass tray.

The discussion of viscosity would be poor without the little "wig-wag" (Fig. 30-16) or some equivalent experiment that all can see. The wig-wag is not easy to make: the quartz fiber must be anchored firmly in a massive support so that little energy is carried away. Students must be warned they will not see the damping entirely independent of pressure. Then, as pressure drops from 1 atm to 0.1 to 0.01, the changes of damping from x to x/2 to x/3 do not seem very serious. Suddenly, at still lower pressure, the damping changes to almost zero. To appreciate pressure-measurement at that stage, students must have previously looked at a M'Leod gauge: we use a huge rough one with oil instead of mercury.

Vapor-pressure, evaporation, boiling can easily sprawl into a long topic that students think dull. I reduce this to teaching by a few problems (11-14), and show a few demonstrations. (The relation between humidity and comfort is important, and deserves a brief discussion.) (The old phrase that, in boiling, the vapor "pushes away the atmosphere" is misleading: the vapor reaching the air diffuses out quite easily; though in bubbles it does have to push against atmospheric pressure.)

We ask one of our research staff to show mirror-making in lab. The demonstration takes 15 minutes: well worth-while.

The idea of an avalanche of ions or electrons, made by ionization by collision, will be needed later (e.g., p. 643); and an early introduction now gives time for it to be digested. The model of Fig. 30-28 helps.

30. PROBLEMS

ESSENTIAL: 2,4,5,6 (as soon as equipartition has been mentioned),

3 (if not done as Prob. 11 of Ch. 25),

8 (assign later, and discuss in class; but do not spend long with specific heats – the yield of good knowledge is almost independent of time spent on teaching. The specific-heat story appeals to abler students and they can read most of it in the text).

IMPORTANT: 9

11+12 (to teach something about evaporation),

13 (a week after 11+12)

14 (if show critical temp., assign this after demonstration).

15 (a good test of using Chapters 25 and 30 together).

17 (if do viscosity expt., result will remain vague without this problem).

See also General problems at end of text, Nos. 24-27.

MINOR: 20 (Difficult. A ball with thin flexible wall stores its energy in thermal form at maximum compression; then most of that is reorganized as K. E. of rebound. In the lead ball the forces between groups of atoms are the shearing forces of friction: the material is carried beyond elastic limit, leaving energy in thermal motion which can not be reorganized into K. E. — there is no receding piston to do that.

Chapter 31. MATHEMATICS: RELATIVITY

(This is intended as optional reading for students with special interests.)

31. AIMS/OUTCOMES

MAJOR AIMS:

To show and discuss uses of mathematics in physics.

To inquire whether mathematics can ever, alone, produce new scientific knowledge.

To give an account of special relativity.

NOTES

I suggest strongly that this chapter should be left for optional reading: volunteers may gain much from it; but others reading for an assignment will not enjoy it because they will worry about learning for tests.

Relativity is mentioned at the end of Ch.1; and again and again there are vague references to it. Some students then ask for clear statements: and this chapter is meant for them. No account of relativity will get very far without a good derivation of the Lorentz transformation. That is avoided here, but should be added in class for students who are capable mathematicians. (A student who could follow the elaborate thought-experiments devised by teachers to evade the algebra of that derivation must have the ability to follow that algebra and should do so with much greater speed and enjoyment.) There is a good version in Einstein's small book published by Methuen (not the one published by Princeton University Press).

Misprints: Footnote * on p. 497 should refer to Probs. 28 and 29 on p. 133. Footnote 23 on p. 498 should refer to p. 123.

Chapter 32. ELECTRIC CIRCUITS

(This is a lab. chapter. If circuits are not done as a series of lab expts. this chapter should be reduced to a few demonstrations — just enough to show the meaning of charge, current and p.d. The treatment of Ohm's Law and power calculations could be omitted.)

32. AIMS/OUTCOMES

ESSENTIAL OUTCOMES:

Students must have good acquaintance with meanings of charge, current, p.d. They must know what a voltmeter measures and how it is used; but they need not know how it works. (This is for electric-field measurements.)

IMPORTANT OUTCOMES:

For all householders, a simple knowledge of amps, volts, watts, kilowatt hours.

Know how ammeters, resistances, voltmeters, etc., are used in circuits.

Calculate power; discuss power-lines.

Meet electrons in diode tube.

32. NOTES

The use of this chapter depends strongly on lab. arrangements. For non-scientists, drill in circuits is unnecessary, irrelevant, and boring — unless it is offered as a series of investigations. That is why circuits are not drawn in detail — and why we ask all lab. instructors to avoid drawing circuits for students — and that is why bridges and potentiometers are omitted; and that is why, when we reach the triode tube, students do not study its characteristics but make it amplify, audibly and visibly.

The apparatus needed for these experiments is not complicated but it is expensive: students need good car-batteries to give constant currents, and good rheostats, and meters that can be read to better than 1% and trusted to 1%.

To keep our apparatus in good order, we must either insert fuses or insist on checking circuits. Fuses offer to degrade good experimenting into silly trial-and-error. So we do without them in most experiments. Instead, students must leave one binding post of battery or supply untouched until an Instructor has "checked" his circuit. Instructor goes quickly to student's table, takes a look, and says yes or no. Yes means "safe," or "we accept responsibility"; but it does not necessarily mean "right." The voltmeter may be in series, the ammeter backwards, the rheostat connected for constant resistance, but student must find that out for himself, correct it and re-check. In this way we safeguard our apparatus well and yet avoid spoonfeeding or cookbookery. Some students find this irritating at first, but enjoy these labs. when they find how much they can learn on their own.

32. PROBLEMS

The following list refers to a course where most of the experiments of Ch. 32 are done in lab. Then the problems are part of the teaching. Without lab., only those problems marked with a * in the list below should be used.

IMPORTANT: 1*, 2 (amazing answers, even after lab).
7*,8*, (may be assigned before voltmeters in lab.).
13+14+15 (?*) (important teaching).
16 (prepares for Prob. 29).
20*,22 or 23,
24*+25*, 26(?*), 27,28*,
29 (after Ohm's Law in lab.), 30 (a week later).
31+32+33,
MEDIUM: 4*,5,6,
9,
34* (if demonstration is then given).

Chapter 33. ELECTROSTATICS

(This is a chapter to reduce, almost to skip entirely.)

33. AIMS/OUTCOMES

ESSENTIAL OUTCOMES:
Simple idea of electric charge.
Conservation of charge.
Idea of electric fields.
Measurement of electric field strength.

IMPORTANT OUTCOMES:
Coulomb's Law.
Pictures of electric field patterns.
Descriptions of triode, oscilloscope.

MINOR OUTCOME:
Coulomb's Law constant.

33. NOTES

I have tried reducing this material to one week or even less. There is no very serious damage. The chapters ahead are far more important from students' point of view, and the only essential contributions later chapters draw on from this chapter are ideas of charge and field strength.

33. PROBLEMS

ESSENTIAL: 14,15,16,
5 (and 17 for calculus students).
MEDIUM: 6,7,10 (if the demonstrations of these are shown),
MINOR: 1,2,8.

Chapter 34. MAGNETISM

34. AIMS/OUTCOMES

ESSENTIAL OUTCOMES:

Review elementary magnetism (learnt in school courses) for needed knowledge of magnetic fields.

Know magnetic fields of coils etc., carrying current.

Know catapult field (for Ch. 37).

IMPORTANT OUTCOME:

Show a simple theory that provides new language.

34. NOTES

Most students have made magnetic field maps with iron filings or at least seen them. Those who have not, should see them in lab. The current fields are important, and the catapult field essential, but these are quickly seen and sketched. So, except for the discussion of theory, the chapter can be left to reading and illustrated quickly in lab. But I regard the simple, old-fashioned, theory of ferromagnetism as so good an example of fruitful theory that I spend most of a lecture on it. The magnetized ring is the crux. It is easy to make a small one (for projection lantern) by softening a piece of clockspring and drilling and snipping it; but it is better to have a big one made of thin die steel, a ring say 4" diameter. Harden the ring, magnetize it by a momentary large current in a wire through central hole; show it has no poles or field; then crack it.

34. PROBLEMS

IMPORTANT: 5.

Chapter 35. CHEMISTRY (A survey for non-chemists)

35. NOTE

In the later chapters on atomic physics there are, inevitably, references to chemistry; and these make students who have not studied chemistry feel at a loss. This chapter attempts to lessen that feeling by describing atomic weights and atomic numbers, and giving a simple account of electrolysis.

I leave this chapter for private reading by those who want it. I show a few examples of electrolysis in lecture, and discuss ions in solution: and then go on to ions in gases.

Chapter 36. ELECTRONS AND ELECTRIC FIELDS

36. AIMS/OUTCOMES

ESSENTIAL OUTCOMES:

Know (from problems) how electrons' v and e/m can be measured.

Know (from problems) how Millikan showed that all charges are multiples of a basic unit.

IMPORTANT OUTCOMES:

Comparison of e/m values for electrons, ions, etc.

Change of e/m with v for high speeds.

36. NOTES

Millikan expt. needs some kind of model to illustrate it. (We use a ballon between huge plates charged by Van de Graaff.) There is a good P. S. S. C. film of actual experiment, but, like the text account, it does not show how the actual electron charge is estimated.

36. PROBLEMS

ESSENTIAL: 1,2 (to introduce the arrangements).

3 (This saves using magnetic field for velocity. Many students fail to read the problem clearly and need further teaching: "traffic lights set for 45 m.p.h.," usually helps.)

4,5,6,7,8.

MEDIUM: 11.

Chapter 37. CATAPULT FORCES

(This is the most difficult chapter, but essential for our advance into atomic physics.)

37. AIMS/OUTCOMES

ESSENTIAL AIM:

To produce a usable expression for catapult force, giving some justification for that expression.

37. NOTES

I know the method used here, of guessing at the force between two current elements is artificial, and the avoiding of the angle factor is poor, but I would rather give a partly experimental introduction than just announce a formula to be used. I have chosen one approach, and the best I can say of it is that I think it no more clumsy and dangerous than the alternative elementary ones. I warn students this discussion will be harsh, not very satisfying; but I assure them it will lead to a result that is essential for our atomic physics. And I promise that the formula (in several forms) will be printed on every examination paper. Unless we show experimental tests, this becomes very poor science. For tests I use the arrangements of Figs. 37-10(b) and 37-15(b)(i).

The text does not say clearly enough that a magnetic field along the motion makes no force. This should be emphasized in lecture.

I show models of moving-coil meter and simple motor, but do no more about them.

It is not essential to measure B, but even a rough measurement makes the whole topic seem more real.

In modifying C_1L_1 to Qv, use n particles (and not just one) to simulate the smooth flow for C_1 – otherwise the logic becomes fuzzier.

37. PROBLEMS

IMPORTANT: 1,2 (important just for practice), 3,4,5,6.

MEDIUM: 7 (if you use the Leybold tube, demonstrate this spiral).

Chapter 38. ANALYZING ATOMS (MASS STECTROGRAPH)

38. AIMS/OUTCOMES

ESSENTIAL OUTCOME:

General idea of sorting out electrons and ions from gas discharge and analyzing them as ingredients of atoms.

Know that mass spectrograph yields clear evidence of isotopes and yields precise values of masses of atoms, and why these are so valuable.

MEDIUM OUTCOME:

Know the working of one or two forms of mass spectrograph.

38. PROBLEMS

IMPORTANT: 1,4 or 5 or both.

MEDIUM: 2,3.

Chapter 39. RADIOACTIVITY

39. AIMS/OUTCOMES

IMPORTANT OUTCOMES:

Knowledge of nature of radioactivity: radiations make ions, and parent element changes to different chemistry; exponential decay.

Properties of alpha, beta, gamma rays.

Working of cloud chamber, counters.

39. NOTES

After Preliminary Prob. 1, I demonstrate cloud chamber and then use slides and prints of photos to illustrate properties and collisions.

I show the sequence of Figs. 39-13(a),(b) to introduce Geiger counter; then use counters to show absorption properties of alpha, beta, gamma rays. (Note: alpha counters are usually sensitive to u.v. light from a lighted match too.)

I discuss and illustrate exponential decay. At this stage it is wise to hang a chart of chemical periodic table on the wall and keep it there.

39. PROBLEMS

ESSENTIAL: Preliminary Prob. 1 (or Prob. 6).

Preliminary Probs. 4,5.

12,13 ((a) equal masses, if elastic; (b) equal charges).

14 (see p. 488), 15 (or Ch. 43, Prob. 2).

IMPORTANT: Preliminary Problem 2 (part (d) is intended to encourage thinking, but the full answer is difficult to work out. See "Ions, Electrons..." by J. A. Crowther for some helpful details. At lower pressure, the first part of the graph rises more steeply, but flattens out to a lower plateau, then starts earlier to rise to spark).

Preliminary Problem 3 (a few ions fail to start a spark, at least for a very long time. A bunch of ions can provide enough electrons, after recombination has removed many, to get into strongest field and start avalanche).

8,16,17,18.

MEDIUM: 7,10.

Chapter 40. THEORY AND EXPERIMENT

40. AIMS/OUTCOMES

ESSENTIAL OUTCOMES:

Students see the development of Rutherford atom model, and some of the evidence for it.

Idea of Z.

GENERAL AIM:

A review.

40. NOTE

I post a huge copy of the table of alpha scattering and discuss it as a Kepler's Law investigation. (I also refer back, now, to Problem 3 in Ch. 18.)

40. PROBLEMS

IMPORTANT: 1.

MEDIUM: 2.

Chapter 41. LABORATORY WORK

(Also provides some account of electromagnetic induction; a little useful reading on radio, – technically quite inadequate – and an introduction to impedance matching.)

In lab we do: Expts. A,C,E, (with D and G optional); Expts. H 1,2,3; Expt. I; and sometimes Expt. J.

Chapter 42. ACCELERATORS

(An extra, optional chapter. I would not use this chapter unless I had some kind of accelerator available for visits.)

42. AIMS/OUTCOMES

AIM: To describe working of cyclotron (and linear accelerator in Problem 4).

42. PROBLEMS

If this chapter is to be studied, Prob. 1 is essential, and it should be assigned a week beforehand.

Problem 4 is intended to give general idea of linear accelerator, but problem has to be followed by class discussion.

Chapter 43. NUCLEAR PHYSICS

43. AIMS/OUTCOMES

IMPORTANT OUTCOME:

Knowledge of nuclear changes; neutrons; positrons. Use of (mass/nucleon) to predict nuclear energy-changes.

MEDIUM OUTCOMES:

Show potential hill models.

Discuss fission and fusion.

43. NOTES

The mass calculation on page 689 is essential, as an example of all such calculations. I post a large version of Fig. 43-34 in lecture and find it useful. With it I post, for the last few weeks, a chart of calculation of 931 Mev per amu (p. 689) — that is too important and useful to be allowed to remain mysterious.

The 1/30 electron·volt mentioned for molecule at room temperature is $\frac{1}{2}mv^2$; the 1/40 ev usually given is kT.

The thought-expt. of Prob. 1(d) is worth going over in class.

43. PROBLEMS (Note that most of the problems on radioactivity are in Ch. 39.)

IMPORTANT: 2,3 (or Ch. 39, Prob. 15).

Chapter 44. PHYSICS TODAY

This is not really a chapter so much as the beginning of a new book: the book or books that I hope students will presently go on to read, ranging from "The Restless Atom" by Romer to "The New Age in Physics" by Massey, or perhaps even tougher books in a further course. That is why I label it seriously as a chapter intended for reading after the course.

In my own course I show photoelectric effect, and discuss matter waves (for which there are films) and end with short discussions of uncertainty and complementarity.

SECTION (VII). EXAMINATIONS AND TESTS

The Importance of Examinations

In some fields of study (e.g., French Grammar) both teachers and students regard examinations as necessary routine burdens that take time and may even help the teaching. In others (e.g., Creative Arts) examinations may do severe damage to the course - the chief benefits of those courses are probably things that cannot be tested in any limited examination; and a test of superficial matters instead would be unfair to good students and damaging to the reputation of the course.

Consider a course in French Literature: there examinations raise an essestial question: test grammar (with ease and accuracy) or test literary appreciation (with difficulty and unfairness)? Many teachers choose the grammar test, and most students prefer it. Yet the important thing for college graduates - whether the course is for their use as future ambassadors or for their general intellectual growth - is an insight into the thoughts and literature of another people - a feeling, perhaps, of "how the Frenchman thinks." The teacher of the course justifies his grammar examination by claiming that "while the test will serve for grades, the real value of the course is in the reading and classroom discussion: and the students know that." Not for long. Even the most inspired student takes count of the tests and draws his own conclusions.

A physics course presents the same dilemma: test information or test understanding? If we are aiming at understanding, as most teachers claim in any physics course, we must examine our examinations very carefully. Suppose we give an inspiring course in which we use well-taught subject matter to show the nature of law, to illustrate a theoretical argument, to establish scientific thinking as reasoning with carefully chosen data. If we then ask in the final examination, "How long does a stone take to reach the bottom of a 40 ft well, from rest?", we deny our own claim. One such question does little damage, and it gives comfort to the students who learned in an earlier course that physics consists of 'putting numbers in the right formula.' It may serve as a discipline measure to enforce reading or study. It also encourages the beginner by offering him a small job to start with that requires practically no thought. Out of kindness, then, we should give a few such questions. But if we give many, in minor tests or major examinations, we shall spoil the course: students will prepare for them; next year's students will hear and pay little regard to our deeper inquires or philosophical discussions - "GET THE FORMULAS AND LEARN THE FACTS THE NIGHT BEFORE THE TEST" will be the advice handed on. And a visitor from another college, who has come to ask about the course, will ask wisely, "May I see your examinations?" Then he will raise his eyebrows and he too will go home unconvinced.

The success of the course depends vitally on the flavor of every test and examination. So we should give much thought to making sure that the questions are as relevant and as inquiring as possible - within the framework of the course. The common custom in large courses of asking each instructor to contribute a few questions of his own invention is pleasant and dangerous. Newcomers to the staff produce new bright questions, but these are often clever rather than simply inquiring. In an inquiring examination the student should not have the additional burden of guessing the examiner's clever intentions. In my own course, I welcome suggestions of questions but I analyze them very carefully for aims and suitability, in conference with their framers. In the first tests of the year I provide many of the questions myself. In later ones, my colleagues delight in beating me at my own game and I am very glad to use the questions they then devise. Many of the problems given as specimens here come from colleagues, who thus helped to maintain the aims of the course.

Examining Physics for Non-scientists

If we are teaching for a sense of understanding science, we should ask questions that inquire visibly into the students' knowledge, ask for reasoning, ask for clear understanding, ask him to describe scientific work. In short, we should give him problems that he can answer if – but only if – he is following the course and achieving some of our aims. Obviously, that "if – but only if" is an ideal of examining that we can only strive towards.

Further, since our most important aims are long-term ones, for benefits that may not mature for months or years, our examinations cannot be tests of full success. The best we can do is to make them encourage success rather than prevent it.

Some questions will ask for recall of information. Only one or two should ask for "cheap recall" of a small item that can be learned by rote. Even those should be useful ones, like

(1) Density of a substance is defined as ....? or

(2) If 1000 kg of brine occupy 0.8 cubic meters, the density of brine in MKS units is

__________ . __________
UNITS

and not ones that just ask for numbers to be put in formulas, like

(3) How long does a stone take to fall from rest down a 40 ft. well?

We begin to require useful thinking when we ask for "expensive recall" – several items of knowledge to be chosen and put together with reasoning or constructive thinking.

(4)(a) A man drops a stone down a 40 ft. well, and measures the time from releasing it till he hears it hit the bottom. Estimate (roughly) the % error he makes by calling this the time of free fall. (Vel. of Sound = 1100 ft/sec.)

(b) Explain how to arrive at your answer.

To assure students that we do not want them to just put numbers in formulas, I issue a public guarantee at the beginning of the course that formulas will be provided free in any examination. In fact, we print many formulas (without explanation) on the front of our examination paper. Nevertheless, the doubting freshman memorizes $s = v_0 t + \frac{1}{2} at^2$ just before the first short test. Then he finds the test begins thus:

(5) In the relation $s = v_0 t + \frac{1}{2} at^2$,
(a) What does v_0 stand for?
(b) What does $v_0 t$ tell us?
(c) Explain where the $\frac{1}{2}$ comes from.

(Thus, the test gives the formula, then asks awkward questions about it.)

In printing the examination, we either ask the student to write his own answer in a blank examination-booklet or give a space for his answer on the question-sheet itself. I prefer the latter for short answers because it indicates the length of answer expected – also because it ties question and answer together for the student's review. (Reducing the question to the standard objective form with a choice among five ready-made answers can damage an inquiring question very seriously; that is almost certain to reduce the question to one needing only cheap recall or clever guessing.) When students compose their own answers, the examination must be graded by physicists – a serious demand, discussed below.

We make each question as inquiring as we can. If we do ask a simple question about a body being pulled along and accelerating, we add a further inquiry: "Would the acceleration be the same on the Moon?, in a freely falling elevator?, under water? Give reasons for your answers." That will often show whether the student understands mass. We soon find that questions asking for descriptions, critical choices or even sensible guesses, can often serve our purpose better than numerical calculations. Examples of these are given later. Half the questions in our main examinations involve little or no calculation. When a question starts with a simple calculation and then asks inquiring qualitative questions about the result, the latter often carry most weight in grading. To critics who object that qualitative questions are "sloppy examining" – I reply, "Please try some. If you make them, you will find that they are not sloppy or easy. And they do reveal what students are learning and thinking, most relevantly."

Still, the feeling remains that among many short questions only the mathematical problems can be made "really hard, to test the best students." That is why I add some longer discussion questions. These are vague general questions relating to the material of the course. Here are some examples:

(A) What are the characteristics of a good experiment? What does a scientist mean when he describes an experiment as good or successful? Give examples.

(B) How did the nature of astronomical theory change from Aristotle to Newton? Describe with examples.

(C) "The kinetic theory of gases is a wild farrago of speculation. It contains as many assumptions as it makes predictions. That is not scientific." Write a short speech as a scientist, either defending or refuting that statement.

(D) What is meant by a law in physical science? (Suppose you are answering the questions of a neighbor in the course who has somehow missed all discussions and reading that relate to laws. He asks, "What are laws? Are they true? What makes nature, or apparatus, obey then,...?").

These questions serve several good purposes. They support our claim that we are seriously concerned with such matters in the course. They give the very good student a chance to show off his skill and knowledge; and they give some weaker students a good chance too, as they feel at liberty to write and do themselves justice. (Other weak students dislike the looseness of the question: then they must depend on the short problems.) But – as my colleagues always ask at examiners' meetings – how can we grade the answers? I suggest:

> "In reading the answers place them in three piles: (a) remarkably good (score 10/10); (b) satisfactory (score 7/10); (c) remarkably bad (score 3/10). Note that there is no single 'right answer': we must accept many varieties of sensible answers, judging more by the way each is justified or illustrated than by its agreement with some official viewpoint. If in doubt, grade an answer (b). There need be no (a)'s or (c)'s unless you find clear cases. If a student shows he has a reasonable view on this important matter he deserves 7/10."

Again and again the readers return, surprised, with three piles of examinations, a small pile of (a)'s, a large one of (b)'s and a small one of (c)'s. I ask if the (a)'s are clear cases, really good. The readers say, "Astounding. These students must have been in some special course." I ask about the (c)'s. The readers reply, "We have checked their names: they are taking the course, but we could hardly believe it. What they wrote is either nonsense or completely wrong."

As an example, consider these three answers to a short, definite question on a part of Ch. 31, "What was Einstein's essential HYPOTHESIS in developing special relativity?"

(i) "That the speed of light is always the same." Grade: (b).

(ii) "That the measured speed of light is always the same; independent of uniform motion of observer or source." Grade: (a).

(iii) "That everything is relative." Grade: (c).

I find that there is a good correlation between these rough grades and the grades for dropping stones down wells, etc. The (a)'s can also calculate and reason. The (c)'s simply have not followed the course. Of course the correlation is far from perfect; and where there are disagreements I welcome the compensations they effect. Even if the correlation were perfect, I should keep these questions, for the sake of students' attitude towards the course, now and in the future.

Examining Physics for Scientists

All physics courses, whether for scientists or for non-scientists, intend to give a lasting understanding of physical science — though their reasons for that intention may differ, and the amounts of factual knowledge they must provide may differ — and they should do their utmost to maintain that intention. There are obvious exceptions, such as crash courses to teach physics to radio-repairmen in an emergency: but those are a matter of training, not teaching science. Some physics courses that are required as auxiliary preparation for other fields (e.g., physics for students of Agriculture,) are often treated like crash training-courses, with a serious loss to education — they could teach less material and give greater understanding and yet yield just as much remembered content at the end. Many students in such auxiliary courses claim that they have no interest or skill in physics and want to keep the course as factual and easily-done-with as possible. Yet, many of them who would rightly resent an increase of technical toughness in physics (e.g., harder algebra) will ultimately respect an increase of intellectual demand. We should demand understanding, but we should scale our standards to students' abilities.

At the other extreme, the eager future physicist, anxious to proceed towards all knowledge and every skill, also needs to understand the physics he is learning. True, a genuine understanding could wait and be developed in retrospect some years later; but the young scientist deserves an insistence on understanding from the earliest stages: otherwise he may become a mathematician or a technician without meaning to.

Physics courses for different kinds of students must differ widely in content and speed and use of mathematical tools; and yet they all have a common need for some characteristics of the new courses for non-scientists; above all, for a modification of examinations. Many a fine course in general physics for physicists, chemists, engineers, and other scientists is well taught, to give thorough training and good understanding, but is then damaged in long-term value by the weekly problems and final examinations. So, although the specimen examination questions that follow are designed for a special course, I offer them with a general moral.

Style of Questions and Their Grading

The value of a question lies in the answer(s) it can elicit, and not in its particular format. Yet some styles of questions make it easier for the student to give the kind of answer we seek (if he knows it). In my course, with its aims, a question may have to be fairly long in wording, to make the examiner's wishes clear. And it should allow considerable latitude in the wording of answers, to give understanding precedence over rote-memory or guessing. So I find the standard objective-test types (True — False, Choose-the-best-answer-among-five, etc.) of little use, and rather harmful. They bring the student back to memorized facts, guessing, clever tricks, ... Even when a five-answer question itself is a good one that asks for expensive recall, the choice among ready-made answers seems to emphasise answers rather than reasoning. We can convince an intelligent student that the reasoning is still being tested, and we can point out the economy in grading; and yet, in the long run, a continuing diet of such questions seems damaging. So I use the following two types of question, with no claim that they are essential or best:

(a) short questions that show clearly what is wanted, followed by a space for the student's answer. In many cases these consist of several parts of increasing difficulty.

(b) general, or vague, questions (usually asking for a long answer), where the student himself sees he has a considerable choice of answers. The best of such questions are those that make every student, — slow, average, and bright, — say, "This is a question I can answer well. I can do myself justice." — although the answers we expect, and get, at different levels differ widely. (A classic example: "Describe what we mean by a scale of temperature." Two examples from my course: "Describe Newton's gravitational theory and its achievements"; "What is meant by a good scientific theory?").

The grading of such questions makes demands on teaching staff. Both kinds described above must be graded by a physicist. Neither a secretary not a machine can judge the students' varying answers, still less give a bright student the extra credit he deserves for a special answer. So I ask my teaching staff to join me in grading all tests and examinations. I explain that I regard that as a major teaching duty. I admit it is a heavy chore, then explain its importance, and receive willing help. (I take a share myself; and I always find that when other senior members of the department join the course to teach they insist on taking their full share).

Examples of Problems and Examination Questions

Some questions that I have used in examinations are printed among the problems at the ends of chapters. Most of the General Problems at the end of the book were originally used, in modified form, in examinations; (in fact, all except Nos. 1,2,12,27,42,47,49, 52,53,54,57.) In judging those problems, readers should remember that we only used a problem when the necessary knowledge for a good answer had been covered in the course. While we ask for imagination, we must be sure to provide the information that is to be used. For example, the "Sunshine Committee" problem (General Problem No. 56, page 768) seems so profitable that we have used it several times; but we changed the "schemes" offered in it to conform with the material in the course that year. (In grading its answers, we accepted, without credit, the student's comment (O.K./?/X) and then gave credit for his defense of it. The whole problem was arranged to be answered on the question-sheet, in a few lines for each part.)

Some specimens of tests and examinations are shown on the remaining pages of this section. Where there are spaces (_____) the answer is meant to be written in that space, on the question sheet. Some long questions ask for answers to be written in an examination booklet, or on separate sheets of paper; and in that case the length of answer expected is not clearly defined.

SPECIMEN QUIZ (given in third week) 25 minutes ①

PLEASE WRITE YOUR ANSWERS IN THE SPACES (____) PROVIDED ON THIS QUESTION SHEET.

1. In the relation $s = v_o t + \frac{1}{2}at^2$,

   (i) v_o means ________________________________

   (ii) $v_o t$ tells us ________________________________

   ____

   (iii) the factor $\frac{1}{2}$ arises because ________________________

   ____

   ____

   (iv) s is the "distance". Suppose a ball is thrown upwards from the ground at t = 0 and rises 25 ft, stops momentarily, then falls back 25 ft to the ground. When it is then back at the ground, what is the value of s ? (25 ft? 50 ft? 0?) . . . . ________________

2. When we explain some event or general behavior, what is the meaning of the word "explain", as used in science, (e.g. as described in Chapter 1) ?

____

____

____

____

3. Here are the records of three cyclists P, Q, R, moving with different motions. They all passed the post A at the instant the clock was started, (time zero). Their distances from A after a total time (from passing A) of 1 second, 2,3,4,5... secs, were as follows, in feet:

CYCLIST	after 1 sec	after 2 secs	3 secs	4 secs	5 secs	6 secs
P	7	14	21	28	28	28
Q	3	9	18	30	45	
R	8	11	9	2	?	

What can you say about the motion of each (not as a vague description, or a detailed diary, but as a clear general statement)?

CYCLIST P ________________________________

____

CYCLIST Q ________________________________

____

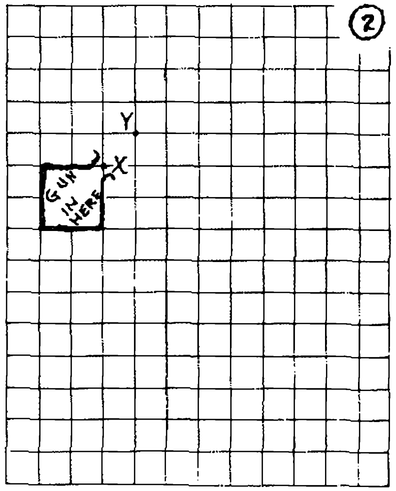
CYCLIST R ________________________________

____

OVER

4. A small gun is clamped in front of a wall on which horizontal and vertical lines are ruled to make squares as in sketch. (The gun's projectiles travel in a vertical plane, parallel to the wall, just in front of it, so their path can be marked on the wall). The gun fires a small steel ball which emerges from the muzzle at X and passes through Y , at the corners of a square, as in sketch.

The ball takes T secs to travel from X to Y . The ball does not rise above the level of Y .



②

   (i) Mark, with dots on the sketch, the later positions of the ball, when it has travelled for 2T secs from X , and for 3T secs from X .

   (ii) Suppose the experiment is repeated in an elevator that is falling freely (cable broken). The gun remains clamped in exactly the same position with same aim, same charge. Mark the path of the ball on the sketch.

   (iii) Describe the path of the ball in (ii), briefly: ________________

   ____

5. We might assume that eclipses of the Moon are due to the Earth getting in the Sun's light, casting a shadow on it. And we might assume that the Sun and Moon have simple orbital motions relative to the Earth.

   (a) What inference(s) concerning eclipses might we make from these assumptions, combined? ________________________

   ____

   (b) What type of inference would this be, inductive or deductive? ________

NOTE ON TIME-ALLOWANCE FOR THIS QUIZ. These questions can be answered quickly by a student who has read the text several times and has the knowledge at his finger-tips: 15 minutes should suffice. A student who has not studied the text but relies on puzzling out some answers and guessing others will need 30 minutes or more. I usually allow rather short time for this first test; and explain that we require finger-tip knowledge.

SPECIMEN MID-TERM EXAMINATION. HALF-WAY THROUGH FIRST SEMESTER. 1 hour ①

Please write your answers in the spaces provided, without explanation unless it is asked for.

Do not spend long on a question that seems hard, but proceed to the next.

Scratch work may be done on the backs of these sheets. It will be ignored in grading.

Answers may be left in factors.

DATA:

Density of water, 1,000 kg./cu.meter, or 62.4 pounds/cu.ft, or 1 pound/pint.

Density of mercury is 13.6 times the density of water.

Acceleration of free fall, g, is 32 ft/sec^2 or 9.8 meters/sec^2.

FORMULARY

$v = v_o + at$ $s = \frac{1}{2}(v + v_o)t$ $s = v_o t + \frac{1}{2}at^2$ $v^2 = v_o^2 + 2as$

$F = ma$ $F\cdot\Delta t = \Delta(mv)$ $\Delta p = \Delta h\cdot d\cdot(g)$ $F/W = h/L$ $P/W = b/L$

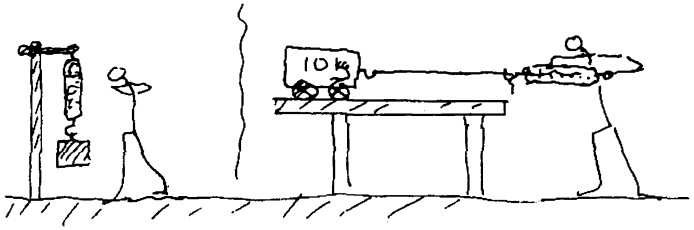
1. (a) One newton is defined as ______________________________

____

(b) The strength of the Earth's gravitational field (near the surface) is 9.8 newtons/kilogram. This means ______________________________

____

(c) A man calibrates a spring balance to read "kilograms-weight" by hanging loads of 1 kg, 2 kg, etc., on it. He then uses the balance to pull a 10-kilogram truck along horizontal rails with negligible friction. The balance reads steadily 2 kg-wt. 3 seconds after starting from rest, the truck will have travelled a total distance of ________ meters.



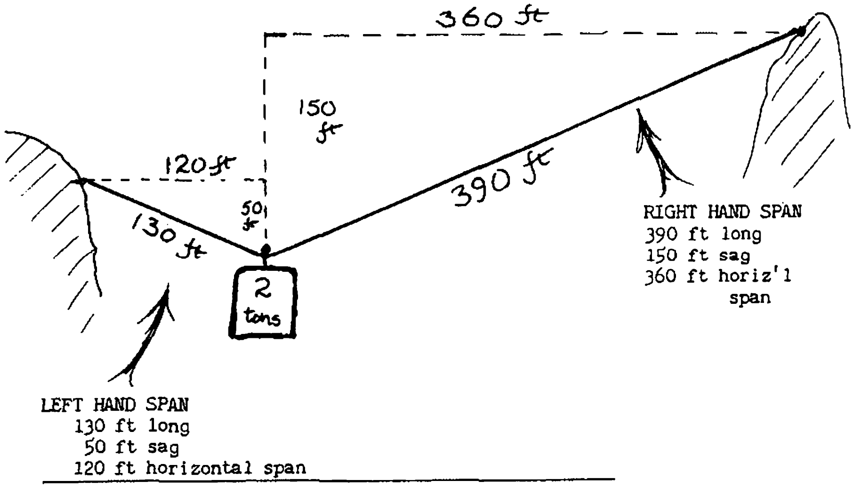
OVER

②

2. A 2 ton cable-car hangs by a frictionless pulley wheel on a steel cable across a valley. (The auxiliary rope that pulls it across is slack.) The car is at rest in the position shown in the sketch, the cable to each side of it making equal angles with horizontal. Find the tensions T_1 and T_2 in the two sections of the cable.

(To obtain credit for correct answers you must sketch a proper force diagram with the forces labelled on it.)

Tensions T_1 = __________.______ units T_2 = __________.______ units



RIGHT HAND SPAN
390 ft long
150 ft sag
360 ft horiz'l span

LEFT HAND SPAN
130 ft long
50 ft sag
120 ft horizontal span

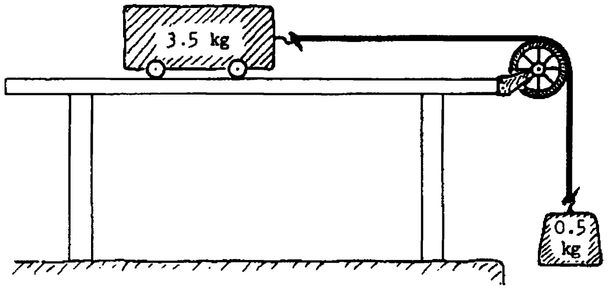
FORCE DIAGRAM HERE

OVER

③

3. (Throughout all parts of the following problem, assume there is no friction of wheels, pulley, etc., and no air resistance.)

The sketch shows a 3.5 kilogram truck being pulled along a frictionless level table by a string which runs over a sturdy frictionless pulley to a load of 0.5 kg.



(a) When it is released from rest, the arrangement's acceleration will be ______________ . ________
UNITS

(b) Suppose the truck is shoved to the left by a firm hand and released when moving to the left. The following motion occurs after the hand has been removed:

- (i) The truck continues to move to the left, on its own, dragging the small load up. The truck moves slower and slower.
- (ii) The truck is momentarily at rest.
- (iii) The truck moves faster and faster to the right, the load descending.

Would you expect the truck's acceleration to be greater than in (a), or the same, or less, or zero?

in stage (i)?______: in stage (ii)?______: in stage (iii)?________.

(c) An experimental test of the arrangement shown, with the table tilted just enough to compensate for friction, gave an actual acceleration for (a) about 10% smaller than the value predicted. Suggest a physical explanation for the disagreement, other than friction, other than air resistance.

____

____

(d) If the apparatus were taken to the Moon, would the predicted acceleration in (a) be the same, greater, or less? __________ Why?________________

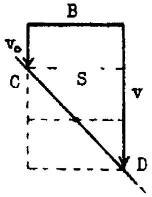
____

OVER

④

4. The sketch opposite shows the diagram used by Galileo in deriving a relation of the form $s = v_0t + \frac{1}{2}at^2$ for uniformly accelerated motion.

The lines representing v_0 and v are marked, and the area representing s is shaded. What does the horizontal line (marked B) represent ?______________



If the slanting line CD had been curved instead of straight, what would that have meant concerning the motion?

____

Which part (if any) of the formula for s above would remain the same in the case of a curved line for CD ? ______________ Why?________________

____

5. Suppose that in your laboratory experiment, investigating some unknown relationship, you find that your plotted points on a certain graph are very nearly in a straight line. Which of the following statements best describes what you should do as a good scientist? (CHECK ONE ONLY)

(a) Examine the distances of the points from the "best straight line" and from these estimate the accuracy of your experiment ..... ______

(b) Explain how you could have done the experiment to make all the points come out on the line.............................. ______

(c) Decide whether the line is or is not an adequate graph for your points by looking to see whether the distances of the points from the "best straight line" are with your estimated error or uncertainty in the measurements............................ ______

(d) Take a lot more more measurements and reject all those which do not give points exactly on the line...................... ______

OVER

⑤

6. Making some reasonable assumptions about dimensions, etc., calculate the pressure in a small rifle while a bullet is being shot out. When a rifle is fired the explosive charge produces a large quantity of hot gas very rapidly; and the pressure of this gas pushes the bullet along the barrel. Make rough guesses about the dimensions of the barrel and any other quantities you need to know, and calculate the average pressure of the gas while the bullet travels along the barrel.
(You are not given measurements. You are asked to invent numbers which seem reasonable, and then calculate a rough numerical answer. Since you must make your own guesses, you must state these guesses clearly before you start using them. Since they are only guesses, only a rough answer is expected -- any reasonable answer will be accepted, provided you explain how you obtain it.)

State clearly: the measurements you choose to assume, and any physical essential principles you use; and indicate your reasoning.

7. A student kicks a half-kilogram football horizontally. The time of contact between boot and ball is measured and found to be 0.010 sec. The ball moves forward across to a wall 5.00 meters away in 0.25 sec.

(a) The ball must have left the boot with horizontal velocity ____________ meters/sec.

(b) The average force between boot and ball during contact must have been ____________ ______ UNITS

(NOTE: The force may be expressed in any units you choose, but you must state the units.)

(c) In flight the ball must have dropped vertically ____________ meters

(d) If the experiment were repeated on the Moon and gave the same measurements as here, would the proper answers for (a), (b), (c) be the same, or much less, or much greater?

(a) horizontal velocity ________, (b) force ________, (c) drop ________

OVER

⑥

8. Describe the meaning and use of "laws" in physical science, discussing examples such as Hooke's Law, the Law of Conservation of Momentum, etc.

(Obviously there is no single right answer to the question "What is a scientific law?" You are invited to give several opinions.)
(Suggested limit: one page).

SPECIMEN FINAL EXAMINATION AT END OF FIRST SEMESTER

3 hours

SECTION A: You are advised to spend $1\frac{1}{2}$ hours on this section, at most, then proceed to Sections B and C, returning to Section A if time permits.

Answer as many questions as you can. Give the answers in the spaces provided, without explanation unless it is asked for.

Do not spend long on a question that seems hard, but proceed to the next.

Scratch work may be done on the backs of these sheets, or on the back pages of answer booklets. It will be ignored in grading.

Answers may be left in factors.

DATA:

Density of water, 1,000 kg/cu. meter, or 62.4 pounds/cu. ft, or 1 pound/pint.
Density of mercury is 13.6 times the density of water.
Acceleration of free fall, g, is 32 ft/sec² or 9.8 meters/sec².
Personal radius of Earth is 4,000 miles or 6.4×10^6 meters.
Personal radius of Moon is about 1,000 miles = 1.7×10^6 meters.
Distance of Moon from Earth is 240,000 miles.
Distance of Earth from Sun is 93,000,000 miles.
The value of G in $F = G \cdot M_1 M_2/R^2$ is 6.6×10^{-11} newton·meter²/kg²
Speed of light 186,000 miles/sec or 3×10^8 meters/sec.
Speed of sound at room temperature 1,100 ft./sec. or 340 meters.sec.
1 month = 27.3 days. 1 mile = 5280 feet.
Mass of Moon = 7.3×10^{22} kilograms. Mass of Earth = 6×10^{24} kg.

FORMULARY:

$S = v_0 t + \frac{1}{2} at^2$ $v = v_0 + at$ $a = v^2/R$ $F/W = h/L$ $P/W = b/L$

$F = ma$ $F \cdot \Delta t = \Delta(mv)$ $\Delta p = \Delta h \cdot d \cdot (g)$

$P \cdot \mathbf{V} = (1/3)\, N m \overline{v^2}$ $S = \frac{(v + v_0)}{2} t$

NAME ________________________

1. (a) How much sand must you place on your hand to feel a force of 1 newton pressing on it? . . . . ________ . ________ unit

   (b) Describe very briefly the experiment and argument that provide the answer to (a) ________________________

   (c) Suppose you travelled to the Moon. Would you need to put the same pile of sand on your hand to feel a newton, or less sand, or more? ________________

2. A central agency, sometime in the future, sends experimenters A, B, C... out to various planets to measure the local acceleration due to gravity, g, at the surface of each planet.

   (i) A reports at the surface of planet P_1 a stone dropped from rest fell about 10 ft. in the first second. "g" there is roughly ______ . ______ units

   (ii) Experimenters B and C go to planet P_2 and make very careful measurements, arriving at answers g = 18.6 and 18.8 meters/sec². Experimenter D, who has applied for a job with the group, is sent to join them and they give him the measurement of g as a test. He obtains 17.7 meters/sec². They calculate his error and report it as 5.32%. Criticise their report.

   ____

   In calculating the percentage error of D, they could divide by 18.6, 18.8, their average 18.7, or by 20. Why is 20 just as good a choice?

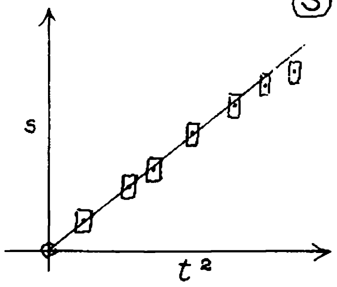
   ____

   (iii) Experimenter E, sent to planet P_3 takes a spring balance marked in kilograms and a standard kilogram with him. He observes there that when his kilogram is hung on the balance the reading is 5.0. What is the value of g there? In reporting his value of g he gives it in newtons per kilogram. The Supervising Government Coordinator objects that g should be in meters/sec². Explain briefly to the coordinator why the units are the same. ________________________

   (iv) Experimenter F measures g with a simple pendulum. His assistant notes that F makes some mistakes in his measurements. In calculating g with the formula $g = 4\pi^2 L/T^2$, he uses a value of L which is 2% too big and a value of T which is 3% too small. His result is therefore about ____% too ______ .

OVER

3. It can be shown by algebra, calculus or geometry, that if $\frac{\Delta v}{\Delta t}$ has a constant value, a, then distance $s = v_0 t + at^2/2$. And for motion starting from rest this reduces to $s = at^2/2$ or $s \propto t^2$.



An experimenter times the motion of a small truck down a slanting railroad, starting it from rest. He plots the results on a graph of s vs t^2 ; and he draws the "best straight line". His points are very close to it. He draws error boxes around them. He then offers each of the following comments:

A. In each case explain briefly why the comment is not a wise or sound one.

(a) "The fact that my points lie close to the line prove that $s \propto t^2$ for motion with uniform accelerations". ________

(b) "The fact that most of my points lie so close to the line shows that some of my error boxes are too big. I must reduce them." ________

(c) "The fact that my points lie close to the line proves that my measurements were very accurate." ________

(d) "The fact that the last two points are off the line shows they are bad measurements that should be erased." ________

B. Suggest a reason (other than chance errors or crooked rails) for the fact that the last two points fall below the line. ________

4. A 4000-pound car is moving steadily along a straight level road. The driver jams on the brakes and the car starts skidding, straight forward at once, and it skids 36 feet in coming to rest, and it takes 3.0 seconds to do that.

(a) Its (negative) acceleration during this skid is ________ . ________ UNITS

(b) The force acting on it to make this acceleration is ________ . ________ UNITS

(c) The external agent which exerts this decelerating force is ________

(d) The car is placed on a level road and pulled ahead by a rope that runs over a pulley and carries a load of iron hanging in a well. With the same brakes

5. A deep-sea diver drops a metal ball from a point just under the surface of the ocean and finds that the distances it falls, from rest, are:
3 ft in 1 sec, 12 ft in 2 secs, (total time): 48 ft in 4 secs.

(a) What can you say about the type of motion? ________

(b) Estimate the distance fallen from rest in 3 secs. ________ft.

(c) Estimate the distance fallen from rest in 5 secs. ________ft.

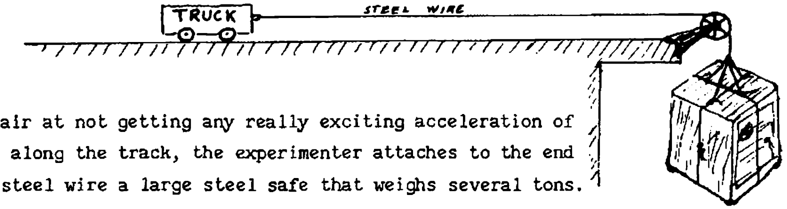
(d) Are the two estimates in (b) and (c) equally reliable? ________

Give a reason for your answer to (d). ________

(e) The diver descends and continues to observe the ball. When it has fallen a long way, he finds it has quite a different motion (before it reaches the ocean floor). What type of motion would you predict for such later stages? ________

Explain your prediction very briefly. ________

6. An experimenter makes a truck accelerate by pulling it with a load hung on a wire over a frictionless pulley, as in the sketch below.



In despair at not getting any really exciting acceleration of the car along the track, the experimenter attaches to the end of the steel wire a large steel safe that weighs several tons. He expects an acceleration of the car along the track several thousand times as great as the acceleration of vertical free fall. Is he right? Why? About how much acceleration do you expect? Be very careful in wording your reply to be as nearly quantitative as you can be without accurate measurements. For example, you might say (wrongly): "The acceleration will be obtained by dividing the acceleration of gravity by several thousand". Give a clear justification for your answer. ________

over

⑤

7. Suppose Kepler had discovered that the planets move in practically circular orbits and obey the law $\frac{R^5}{T^2}$ = constant , instead of the Law III that he did find. What law of force would Newton have had to use to account for such a solar system? Give your reasoning, briefly, in the space below.

Law of force: Instead of $F = G\,M_1M_2/R^2$, F = ______________

8. A large smooth stone rests on a frictionless level frozen pond. A man stands in the center, anchored to a stake, and holds a rope that is attached to the stone. Having given the stone some motion to start with, he then lets it move in a great rectangular orbit, as shown in the sketch. He makes the stone follow this path by giving the rope a violent tug at certain instants.

(i) At what stages does the man give a tug?

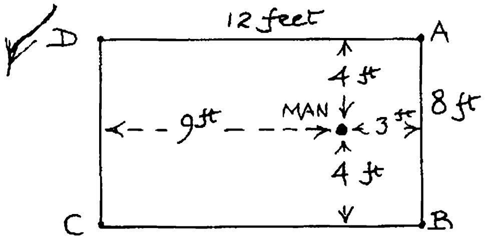
(ii) How do you know that the man leaves the rope slack the rest of the time and does not pull? ______________

(iii) How does the stone's speed change during its trip along AB? ______________

(iv) If the stone takes 2 secs to travel the 8 ft from A to B, how long will it take to travel the 12 ft from B to C? T_{BC} = _____sec

How long will it take to travel the 8 ft from C to D ? T_{CD} = _____sec

SHOW YOUR WORKING BRIEFLY IN THE SPACE BELOW. YOU NEED NOT EXPLAIN IT.



⑥

9. (i) Kepler put forward his "Law 0" (with the five regular solids) as a theory or conceptual scheme to explain or predict something. What? (Say what he was trying to predict. No need to say how the scheme was arranged.)

(ii) Why do we now consider that a poor, bad or unsatisfactory theory? (Give as many reasons or objections as you can.) ______________

(iii) What, if anything, can you now say in its favor? ______________

10. In lecture you saw the speed of a rifle bullet measured. You could make a similar measurement in laboratory. You would be provided with the same truck containing a large chunk of wood, running on rails, with almost frictionless wheels. Instead of the electric eye, you would be given a stopwatch. Describe the measurements you would make and show how you would calculate the bullet's velocity from your measurements. If time permits, mention any special precautions you would take to ensure accuracy.

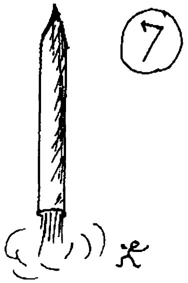
(Write your answer below, continuing on the back of this sheet.)

OVER

11. A 12-ton rocket is launched vertically upward. The downward velocity of the exhaust gases is 3000 ft/sec.

(a) How many pounds of exhaust gases must flow out per second if the rocket just hovers suspended in mid-air?
(You may leave answer in factors.)

(To save yourself from losing all credit for wrong answers, you should write your working in the space below, but you need not explain it.)



Flow = ____________________ pounds/second.

(b) What flow would be needed to give the rocket an upward acceleration of 32 ft/sec/sec?

Flow = ____________________ pounds/second.

(c) How long would it take the rocket with this upward acceleration to reach sonic speed, 1100 ft/sec, starting from rest?
(Neglecting air resistance)

time = ______________ seconds.

SECTION B: Please answer this question in an examination booklet. You are advised to spend at least 30 minutes on this. Give large clear sketches to illustrate your answer wherever possible.

B. Discuss the role which theory plays in science, drawing on Newton's theory of gravitation for illustration as freely as you wish. (Some suggestions of points to deal with are: What makes a good theory? How is it used? What makes it useful? These are only suggestions; you may wish to include others.)

C is on the next page.

SECTION C: Choose one of the following problems, C.1 or C.2 or C.3.
Answer the problem in an examination booklet showing your reasoning clearly. You are advised to limit your time for this to 30 minutes.

C.1. Describe any two of the measurements listed below. In each of the two you choose,

(a) describe the method and/or apparatus (with clear sketches where possible,
(b) list the assumptions made in using the apparatus or in working out the result,
(c) say clearly what measurements are made, and explain how the result is worked out from them.

CHOOSE TWO.

(i) Estimate of length of an oil molecule
(ii) Measurement of radius of the Earth
(iii) Measurement of distance of Moon from Earth
(iv) Measurement of gravitation constant G (not g)
(v) Estimate of ratio of orbit sizes for, say, Venus and Earth.

C.2. (a) Show that a point moving with speed v round a circle of radius R has acceleration v^2/R towards the center. Explain your proof carefully.

(b) The proof asked for in (a) is just a piece of geometry. The result does not itself tell us about the real world which science studies. When combined with one of Newton's Laws, it does make a statement about the real world. What is that statement?

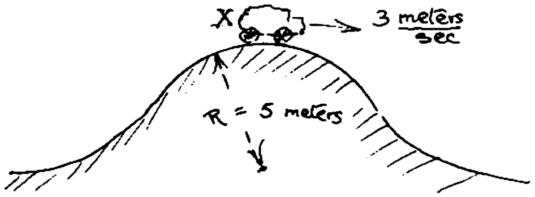
(c) A roller coaster loops the loop on a track bent into a suitable vertical circle. Describe the real forces acting on the car at each stage: bottom of loop, half way up, top. Give clear diagrams showing the direction of each force. (Since no numerical data are supplied, no calculations are asked for, but just a general description.)

C.3. What would you mean, as a scientist, if you described an experiment as a good experiment, or a successful one?
(Obviously, there is no single right answer to this. You are invited to give your own opinions and comments to, say, an intelligent non-scientist who says, "How do you know whether you are experimenting or just playing around with apparatus; and what is the difference between research and routine technical measurements". Give examples from your work in this course if you like.)

SPECIMEN SHORT QUIZ   After Chapter 21   20 minutes ①

1. A car is driven at constant speed 3 meters/sec along a level road and up and over a hump-backed bridge, (of vertical) radius 5 meters as shown in sketch.

The car maintains good contact with the road all the way over the hump.
Total mass of (car + passengers) is 2000 kg.



(a) List below all the real forces that act on the (car + passengers) when it is at X , the top of the bridge.
(You may neglect air friction and air buoyancy here.)

FORCE	DIRECTION

(b) Calculate the resultant force acting on the car at X , and state its direction (up/down/forward/backwards).

Force = ________ . ________ in direction ________.
UNITS

(c) Now suppose the trip is repeated at greater speed. The car is now proceeding at such a speed that the passengers notice that it just leaves the road at X (they feel no bumping from the rough road, and on leaning out notice a little air under the tires).
Calculate the new speed of the car

V = ________________ m./sec

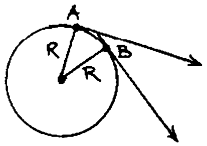
OVER

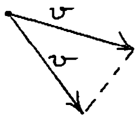
---

②

2. The derivation of $a = v^2/R$ is shown, without explanation, below.

$$a = \frac{v\cdot\overline{AB}}{R\cdot\Delta t} = \frac{v}{R}\cdot\frac{\widehat{AB}}{\Delta t}\cdot\frac{\overline{AB}}{\widehat{AB}} = \frac{v^2}{R}$$





(i) In the final step (across the last = sign) what value is given to the quantity $\widehat{AB}/\Delta t$; and why?________________

____

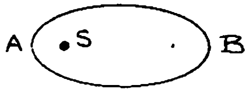
(ii) In the final step, what value is given to $\overline{AB}/\widehat{AB}$; and why?

____

____

____

3. A planet moves in an ellipse, with Sun at one focus, S , as in the sketch.



According to Kepler's Law II ("equal areas"),
the planet moves ________________
faster/slower/same speed
at A , nearest Sun compared with its motion at B (farthest from Sun).
The radius of curvature of an ellipse is the same at both ends, A and B .
What can you infer concerning the force exerted by the Sun on the planet at A compared with the force at B . Explain your reasoning clearly.

____

____

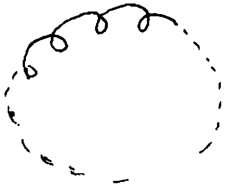
____

____

____

TEST (late in first half year) 60 minutes ①

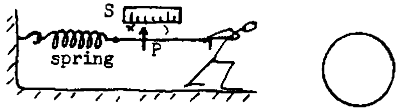
1. The path of Jupiter through the star pattern appears to be an epicycloid (see sketch). Describe, with sketches, the way in which this path was accounted for (a) by Ptolemy, (b) by Copernicus.

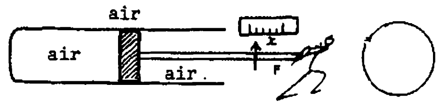


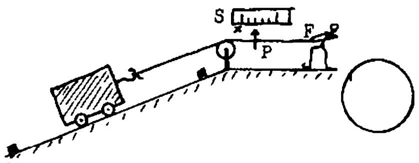
OVER

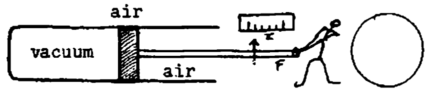
2. Each of the sketches below shows some device or apparatus in which an applied force F produces some displacement (movement, or stretch, etc), x . In each case, the pointer, P, starts at zero on the centimeter scale, S, when no outside force is applied; and x is measured from that zero to the position of P with various forces, F . ②

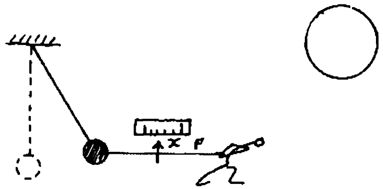
The graphs sketched suggest various relationships between F and x which might be observed. For each device, choose the graph which you think shows the relationship between F and x most truly, and write the number of that graph in the ring opposite the device.

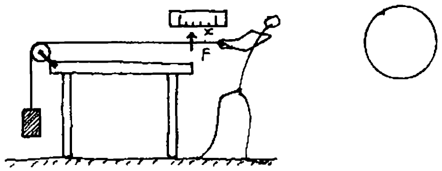


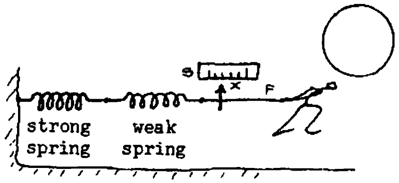


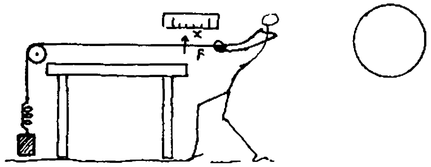


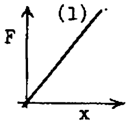


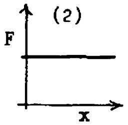








(1)


(2)


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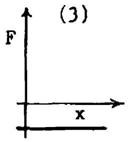

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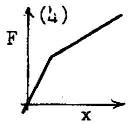

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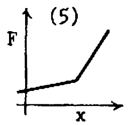

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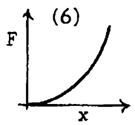

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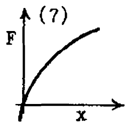

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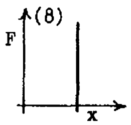

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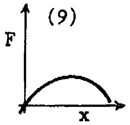

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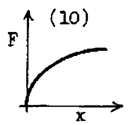

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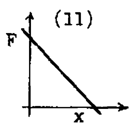

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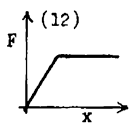


SPECIMEN TEST ON LABORATORY TOPICS (late in first half year) 30 minutes ①

(This is not a "laboratory exam" to test experimental skill or knowledge of techniques. It is an ordinary quiz on some topics that happen to be taught in laboratory. In practice these questions are not placed in a special quiz but are incorporated in ordinary tests and examinations. They are segregated here because their choice depends on the actual program of laboratory work.)

1. (i) A pendulum consisting of a massive bob on the end of a long light thread is suspended in a laboratory and set in motion with an amplitude of 5 degrees. The period is then measured.
What effect on the observed period would you expect to observe when you made each of the following changes? (Each change alone, without the other changes)

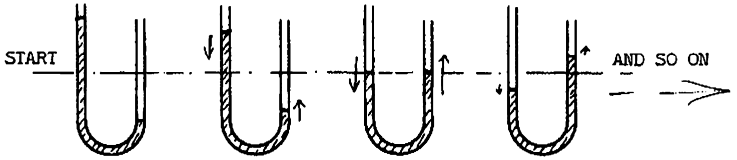
(a) decrease the amplitude to 2° ______
(b) increase amplitude to 60° ______
(c) double the mass of the bob ______
(d) double the length of the string ______
(e) move pendulum to moon ______
(f) move pendulum to an elevator which is accelerating steadily upward ______

(ii) Given the "formula" $T = 2\pi\sqrt{L/g}$ for a simple pendulum, you can use pendulum timings to measure "g". Why is this a much better method of obtaining a reliable value of "g" than, say, timing the fall of a ball from the ceiling to the floor with an electric clock?

over

②

2. Some water is placed in a large U-tube with open arms. If the water is pushed down on one side (by blowing) and then released, it oscillates. The sketches show stages of this motion.



(a) Explain why you would expect this motion to be isochronous (with period independent of amplitude). ______

(b) Suppose the water is replaced by an equal volume of mercury. Explain why the period of oscillations is just the same as before.

(c) The U tube with water is taken to the Moon, where "g" is only about 1/6 as big. Would you expect the period of oscillations to be the same as on the Earth, or less, or more?. . . . . . . ______
Why? ______

3. Suppose an experimenter travels by rocket to another planet and wishes to measure "g" there. Through incompetent packing his clock for timing free fall is broken in transit; but he arrives with two barometers in good working order. Barometer A is an ordinary mercury barometer with its scale marked in inches. In barometer B the atmosphere pushed a piston against a good steel spring; so that atmospheric pressure is measured by the distortion of the spring. The scale of B is marked in "inches of mercury". In the laboratory on Earth both barometers read 30 inches before starting. On arrival at the other planet, barometer A (mercury) reads 45 and barometer B reads 90. Estimate the value of "g" there.

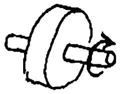
g = ______ . ______ units

QUIZ ON ENERGY (early test of reading Ch. 26 - 28) ①

1. One joule is a unit of ____________. It is the same as one ___________.

2. A charge of explosive is fired behind a bullet in a gun. The explosion is finished long before the bullet has travelled far along the barrel. Describe the form of the explosive's energy: (a) before firing ________________
   (b) after firing, but before bullet has moved an appreciable distance along barrel ________________
   (c) when bullet emerges ________________
   (d) Explain carefully the mechanism by which energy is converted from its form in (b) to its form in (c) ________________
   ____
   ____

3. Spin energy is the energy that a rotating body has on account of its spin. Explain what the spin energy of a rotating wheel *is*, in terms of another form of energy.



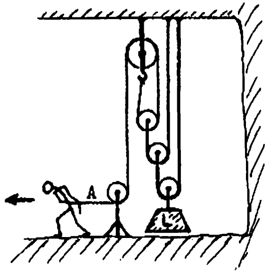
____
____

A certain wheel, rotating 10 revolutions/second has some spin energy. When the same wheel is rotating 20 revolutions/second its spin energy is _____ times as great as before.

4. Heat energy of a gas is the energy given to it when it is warmed up by flames, etc. Explain what heat energy of a gas *is*, in terms of another form of energy.
____
____
____

②

5. A man uses the pulley system shown opposite to raise a heavy load L .
He can pull with a force of 30 pounds-wt on the horizontal rope A .
If the pulleys have negligible weight and negligible friction, what load can he raise?
__________pounds



He pulls the horizontal rope with a force of 30 pounds and walks away at speed 3 ft/sec.
With what speed will the load rise? _____ ft/sec.

Write IN FACTORS, the rate at which the man is supplying energy to the pulley system, expressed in HORSEPOWER ________________HP

Write IN FACTORS, the rate at which the load is gaining energy, in HORSEPOWER ________________HP

Where does the energy gained by the load come from, in the procedure described?
____
____

If the ropes break, through what changes is the energy that the load has gained likely to go?
____
____

6. A lead bullet is fired at a massive wall and stops dead. As it stops its temperature rises.
   (a) How would the temperature-rise be affected if we doubled the bullet's original speed?
   ____
   (b) Explain how you reached your answer to (a)
   ____
   (c) How would the temperature-rise be affected if we used a bullet of twice the mass, but original speed? ________________
   (d) Give a clear reason for your answer to (c).

HOUR TEST ON CHAPTERS 25-30

1 hour ①

1. One watt is a unit of ________ . Expressed in other MKS units it is one ________ .

2. An elevator and its passengers make a total load of 2000 kilograms. It is moving upward with constant speed. It passes the 7th floor moving 2 meters/sec. It passes the 9th floor 3 secs later, still moving 2 meters/sec. In the travel from the 7th floor to 9th floor

   its gain of potential energy is ________ . ________ units

   its gain of kinetic energy is ________ . ________ units

   the power it takes from the driving motor is ________ . ________ units

3. (i) A 6000-kilogram car runs down a hill, with negligible friction, starting from rest. After it has run down to a position 20 meters lower, vertically, than its start, its speed will be ____________ meters/second.

   CALCULATE THE SPEED BY A METHOD THAT USES ENERGY-CONSERVATION AND SHOW YOUR WORKING OF THE CALCULATION BRIEFLY BELOW. YOU NEED NOT EXPLAIN IT.

   DATA: "g" ≈ 10 newtons/kg   1 Cal ≈ 4200 joules

   (ii) The same 6000-kg car rolls down a hill starting from rest, but with its brakes loosely applied. When it has run to a position 20 meters lower, vertically than its start, it is found that the car's wheels+brake+shoes, of total mass 500 kilograms and specific heat 0.10 have been heated up from 18° to 22°C .
   Assuming that the wheels have had no chance to be cooled appreciably by air, etc., calculate ROUGHLY the speed of the car. SHOW YOUR CALCULATIONS CLEARLY BELOW.

   speed = ______________ meters/sec

OVER

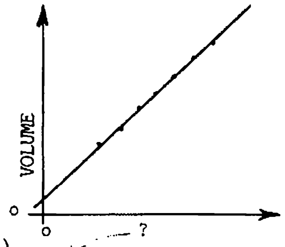
②

4. (a) Kinetic theory, making some plausible assumptions suggests that PRESSURE·VOLUME should be constant for a sample of gas at constant temperature. The simple theory assumes that molecules do not interfere with each other except in extremely brief collisions. Now modify that and suppose that molecules do interfere noticeably, by being large enough to get in each others' way or by attracting each other when fairly close. In that case we expect Boyle's Law would not quite fit the facts. Would you expect to find Boyle's Law failing noticeably for such a gas at small volumes (high pressure) or at large volumes?

   ________________ small vol / large vol ?

   Explain briefly why. ________________________________

   (b) An experimenter studying the relation between PRESSURE and VOLUME for a sample of air at constant temperature obtains some accurate measurements and plots them on a graph. He plots VOLUME upwards. He wishes to have a "straight line graph". From your knowledge, say what he should try plotting along, calculated from his pressure measurements. (That is, should he plot P or P^2 or $\sqrt{P}$ or what?)



   ________________ along

   He plots his graph and draws a "best straight line" as close to the experimental points as he can. What is his purpose in drawing that line?

   Now notice that the straight line cuts the vertical axis at a small value of volume (not zero volume). Guess the physical interpretation of this fact.

OVER

5. The kinetic theory of gases predicts that $P \cdot V = (1/3)\ N\ m\ \overline{v^2}$

(a) Explain the presence of the factor 1/3 ______________________

(b) What does $\overline{v^2}$ stand for? ______________________

(c) Two gases, A and B, have molecules of the same mass but different sizes; molecules of A are fatter, having 3 times the diameter of molecules of B. Explain why the travel-distance between collisions is quite different for A from its value for B, at the same temperature and pressure. (NOTE: when there is a head-on collision, the fatter molecules save a little travel-distance because they hit a little earlier than smaller ones would; but, with molecules far apart -- as they are in gases at ordinary pressure -- that is trivial: it is NOT the answer to this question.)

6. How long would you take to raise a load of one ton through a height of one story? Make sensible guesses at any data you need, and show how you arrive at your estimate.
(You may use any pulleys, etc., that you wish, but not any other helpers such as electric motors. Make any guesses or assumptions that seem reasonable, but state them clearly. Explain your working briefly. Since detailed data are not provided, your answer must be a rough one. It will be judged on general reasonableness and clearness of working.)
Write your answer below, continuing on the back of this sheet.

SPECIMEN MID-TERM EXAMINATION (middle of second half year) 1 hour

Please write your answers on these question sheets in the spaces provided.
Answers may be left in factors.
Scratch work may be done on the backs of these sheets. It will be ignored in grading.

DATA. SOME OF THE FOLLOWING MAY BE USEFUL:

1 Å.U. = 10^{-10} meters
1 Calorie = 4200 joules
Acceleration of free fall = 9.8 meters/sec^2 = 32 ft/sec^2
Strength of earth's gravitational field near surface = 9.8 newtons/kdg
Absolute zero is at -273° on ordinary centigrade scale
Specific gravity of mercury = 13.6
Density of water = 1000 kg/cu.meter
1 H.P. = 550 ft.lbs/second = 746 watts
Charge on an electron = -1.6×10^{-19} coulomb

FORMULARY

$v = v_o + at$ $s = v_o t + \frac{1}{2}at^2$ $s = \frac{1}{2}(v+v_o)t$ $v^2 = v_o^2 + 2as$

$\Delta(P.E.) = W \cdot h$ $K.E. = \frac{1}{2}mv^2$ $E = mc^2$ $P \cdot V = (1/3)\ N m \overline{v^2} = RT_{gas}$

$\frac{1}{2}m_A v_A^2 = \frac{1}{2}m_B v_B^2$ $L = D^3/\pi d^2$ $(p + a/V^2)\ (V - b) = RT$

$\text{heat} = M_{water} \cdot \Delta(\text{temp})$ $\text{heat} = M \cdot \Delta(\text{temp})\ (\text{sp.heat})$ $F = 9 \times 10^9\ Q_1 Q_2/d^2$

1.
(a) One watt is a unit of __________. Expressed in terms of other MKS units, it is the same as one ______________________

(b) One electron·volt is a unit of ________. It means ______________________

Expressed in terms of MKS units its value is ______________________

(c) When we say an electric field has a strength of 1000 newtons/coulomb, what does that mean? ______________________

(d) Explain why a strength of 1000 newtons/coulomb is the same as a strength of 1000 volts/meter. ______________________

(e) Do you consider electric field strength to be a vector? ______________________
Why? ______________________ OVER

②

2. (a) An electric motor takes 10 amps from a supply. THIS MEANS THAT ______

______

The P.D. of the supply is 120 volts. THIS MEANS THAT ______

______

(b) The power input for the motor in (a) is ______ . ______ UNITS

(c) The motor is used to raise a small elevator of mass 60 kg. If the motor is 70% efficient, how long will it take to raise the elevator 6 meters? (To avoid losing all credit through careless mistakes, you should write your work in the space below, but you need not explain it.)

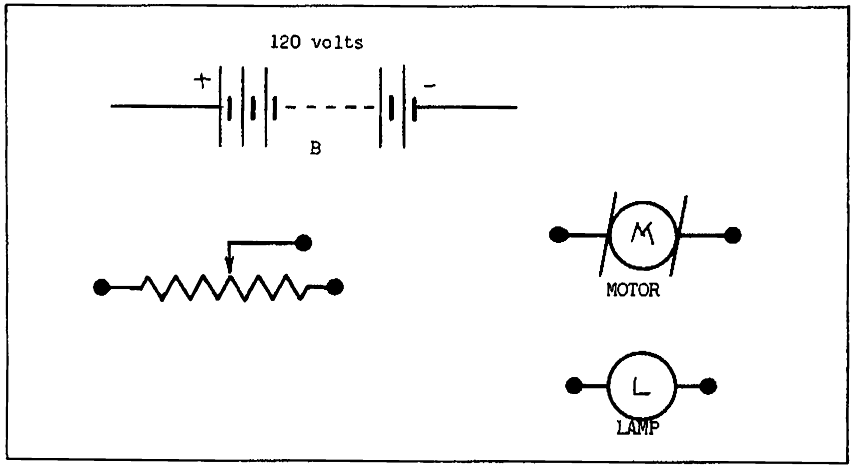
LEAVE ANSWER IN FACTORS time = ______ seconds

(d) An engineer wants to run a 120-volt electric motor, M, from a 120-volt battery, B. He also wants to run a 120-volt lamp, L, from the same battery, with a rheostat, R, so that he can have the lamp anywhere between fully bright and very dim (without affecting the motor). In the space below, use B, M, etc., already drawn and draw the circuit he should use, including the following:

an ammeter A_1 to measure the motor current

an ammeter A_2 to measure the lamp current

a voltmeter V placed so that it measures the voltage for the lamp only.



(e) Make a + mark on each of the meters (A_1, A_2; V) to show the binding post of the meter that the makers would label "+" according to their usual custom.

OVER

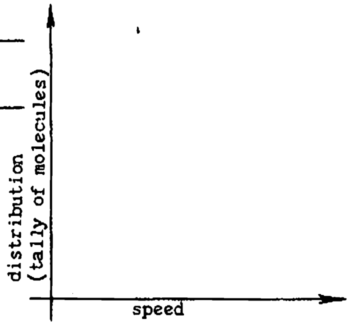
③

3. Two boxes A and B, each of volume 24 cubic meters, each contain gas at room temperature, each at pressure 1 atmosphere. Box A contains 32 kg of oxygen. Box B contains 2 kg of hydrogen. The oxygen in box A is taken out, cooled, compressed and cooled to liquid and placed in box B with the hydrogen gas. The liquid oxygen evaporates, and the mixture of gases in box B finally reaches room temperature again. The following questions relate to that mixture in box B at room temperature:

(i) $\dfrac{\text{average K.E. of oxygen molecules}}{\text{average K.E. of hydrogen molecules}} =$ ______

(ii) $\dfrac{\text{average speed of oxygen molecules}}{\text{average speed of hydrogen molecules}} =$ ______

(iii) Sketch the distribution of speeds of oxygen molecules on graph opposite, using a broken line (---------)
Sketch the distribution of speeds of hydrogen molecules on graph opposite using a solid line (————)



(iv) What will the pressure be in the box B ?
(Compared with original atmospheric pressure) ______

4. (a) Describe the way in which a gas-thermometer, such as the one sketched, is calibrated (= arranged to measure thermometer). How is it then used to measure the temperature of a bath of hot water?

______

______

______

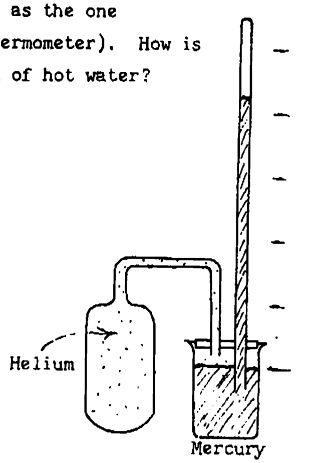
______

______

______

______

______



(b) What is the significance of finding that (PRESSURE) ∝ (ABSOLUTE TEMPERATURE) for many different gases maintained at constant volume, the gas-thermometer of part (a) being used to measure temperature? ______

______

______

______

______

OVER

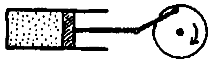
5. (a) A gas in a cylinder with a frictionless piston is suddenly compressed by a man ④ pushing the piston inward. The gas grows hotter.

(i) In terms of molecular behavior, by what mechanism or process does the gas grow hotter?

(ii) Where or what is the heat that is gained?

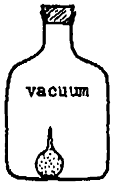
(iii) Where does the heat that is gained come from? What provides it? (NOTE. The piston grows no cooler.)

(b) A compressed gas in a cylinder with a movable piston is allowed to expand by pushing the piston out. Explain briefly why gas cools.



If the piston is connected to a frictionless flywheel, what happens to the heat lost by the gas?

(c) A small capsule of compressed gas is placed in a large bottle from which all air has been pumped out, so that there is a vacuum. The capsule splits open and releases the gas. Explain why in this case you would NOT expect to find the expanded gas any cooler.



(d) Most real gases do show a small cooling when released as in (c). What does this suggest regarding the molecules of such real gases? (HARD. Make an intelligent guess and give a brief reason for it.)

OVER

6. During the 19th Century the view that heat is a form of energy and the general ⑤ law of Conservation of Energy were established by series of experiments carried out by Joule and others.

(a) What was the general scheme of procedure, common to most or all of the experiments?

(b) Why were many varieties of experiment considered necessary?

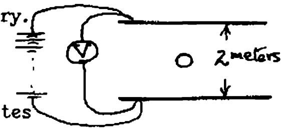
(c) Select two of those experiments and describe them in detail (excluded from this choice: your own laboratory experiments). (Give a sketch to show the scheme of apparatus. Say how it was used, what measurements were made, and how the measurements were treated to produce evidence for the general idea.) (Limit 1 page each.) (You may continue on the back of this and on a blank sheet.)

QUIZ ON CHAPTER 33   ELECTROSTATICS   30 minutes   ①

1. (a) The field-strength of an electric field is defined as ________________
____
____

(b) and the usual units for it are ____________ or ____________

(c) Two very large parallel plates of metal are placed 2.00 meters apart, as shown in the sketch, and connected to a battery. A voltmeter connected to the plates reads 100,000 volts.
The field-strength in the region between the plates

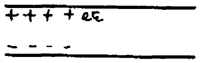


= ______________ . __________
units

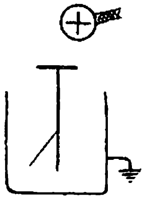
(d) A balloon charged with + 10^{-7} coulomb placed between the plates just floats without falling. The force exerted on the balloon's charge by the electric field must be . . . . ____________ . __________
units

(e) If the balloon were taken out, and placed (uncharged) on a weighing scale, the reading would be __________________kg.

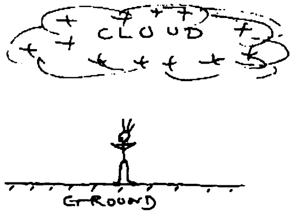
2. In each of the sketches below, draw about a dozen lines of force to show the general pattern of the electric field; and mark + and - signs where there are charges.



A pair of parallel
flat metal plates.
The top one is
charged with a
+ charge. The lower
one has an equal
- charge.



A metal ball with
+ charge held near
electroscope which
was uncharged.
(outer case grounded)



Very tall man standing under
a thundercloud with + charge.

②

3. Give a "theoretical argument" to show that: if the law of force between electric charges is an inverse-square law, we should expect to find no electric field anywhere inside a hollow metal sphere that has been given a charge.
(Illustrate your argument with sketch(es) and point out any additional assumptions you make.)

SPECIMEN QUIZ ON CHAPTER 40 — 20 minutes ①

1 (a) What was Prout's suggestion long ago concerning masses of atoms?

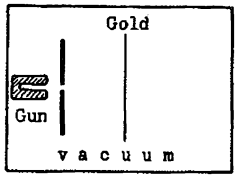
____

(b) What measurements involving chlorine gas led to Prout's idea being abandoned?

____

(c) What discovery led to Prout's idea being revived? How did this deal with the "chlorine difficulty"?________________________

____



2 (a) The sketch opposite shows alpha rays being fired at a thin gold leaf. On the sketch, sketch many alpha rays emerging from the gun, and show what happens to them.

(b) What is inside the gun?________________

(c) Why is no voltage applied to the gun?__________

____

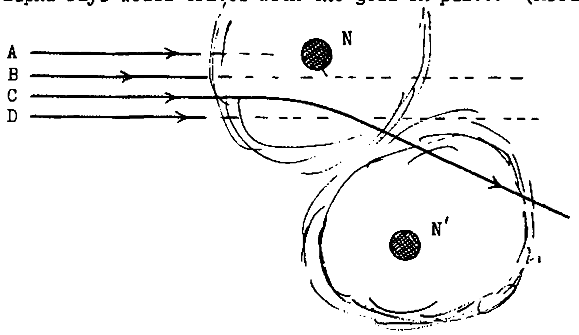
(d) Why is this experiment done in a vacuum?________________

____

(e) From this experiment, we can infer at once that the gold nucleus (or some such thing) must have a mass greater than the mass of an α-particle. What observation is alone sufficient to tell us this?

____

3 The sketch below shows gold atoms being bombarded by alpha rays. The lines A,B,C,D, are the paths of individual alpha rays approaching the gold atom's center, N . N' is another gold atom's center. The broken continuations of A,B,D show how those tracks would continue without the gold. The line C shows one track with the gold in place. Continue the other tracks, A,B,D to show roughly how you expect their alpha rays would travel with the gold in place. (Assume the other gold atoms are far away.)



OVER

4. In dealing with the scattering of alpha particles Rutherford, and others made some assumptions and arrived at the prediction:

$$N = \frac{K\cdot(\text{area of screen})\,(2e)^2\,(Ze)^2}{v^4}\cdot\frac{1}{(\sin A/2)^4}$$

(a) In this, e stands for ________________

A stands for ________________

v stands for ________________

Z stands for ________________

(b) What experiments were done to test the values of Z ?

____

____

____

(c) Such experiments showed that Z is (probably) the same as a number which was already known, i.e., the number which tells us________________

____

(d) According to the predicted relation, $N\cdot(\sin A/2)^4$ should be constant in certain experiments, and actual measurements agreed well with this prediction. What did this agreement tell us about atoms?

____

____

(e) In fact the results of the test (d) above ran thus for a great series of experiments: 29,31,29,28,29,30,31,33,35,29,30. These results are not quite constant (i.e., they are not all the same). Yet physicists consider the experiments agree "very well" with prediction. Give a good reason for calling such results as these very good.

____

____

(f) Suppose you could not do the mathematics of deriving Rutherford's predicted formula, but proposed to use common sense + physics instead.

(i) Why would you expect to find N greater for greater Z ?

____

____

(ii) Why would you expect to find N greater for smaller v ?

____

____

____

②

SPECIMEN FINAL EXAMINATION AT END OF SECOND HALF YEAR 3 hours

①

DATA:

Electron charge = 1.60×10^{-19} coulomb

Mass of proton = 1.66×10^{-27} kilogram

Mass of electron = 9.0×10^{-31} kg, or $\frac{1}{1840}$ mass of proton

e/m for electron = 1.76×10^{11} coulombs/kilogram

e/M for hydrogen ion or proton = 95,700,000 coulombs/kilogram

940 Mev is equivalent to 1 proton

931 Mev is equivalent to 1 atomic mass unit

Velocity of light = 3.0×10^{8} meters/sec or 186,000 miles/sec

1 coulomb deposits 0.000000329 kilograms of copper in electrolytic bath

1 horsepower = 550 foot·pounds/sec or 746 watts

1 Calorie = 4200 joules 1 A.U. (Ångstrom unit) = 10^{-10} meter

Specific gravity of mercury = 13.6 Density of water = 1,000 kg/cu. meter

Strength of Earth's gravitational field near surface = 9.8 newtons/kg

Absolute zero is at -273° on ordinary centigrade scale

FORMULARY: $v^2 = v_o{}^2 + 2as$ $v = v_o + at$ $s = v_o t + (1/2)at^2$

$\Delta(P.E.) = W \cdot \Delta h$ $KE = (1/2)mv^2$ heat = $(M_{water}) \cdot \Delta T$ heat = $M \cdot \Delta T \cdot$(specific heat)

$P \cdot V = (1/3)Nmc^2$ $(1/2)m_A v_A{}^2 = (1/2)m_B v_B{}^2$ $L = D^3/\pi d^2$

Power = C^2R $E = C^2Rt$ $H = C^2Rt(4200$ $F = Ma$ $F = Mv^2/R$

Electric field, $X = V/d$ $F = XQ$

Force in newtons between charges Q_1 coulombs and Q_2 coulombs, distance d meters apart, is $B \cdot Q_1Q_2/d^2$ where $B = 9 \times 10^9$.

Force on a charge moving in a magnetic field: If magnetic field is made by current C amps flowing around coil of N turns, radius R meters, the magnetic field, H, at center of coil is given by $H = 2\pi\ NC/R$ amp·turns/meter.

Charge Q coulombs moving across the field with velocity v meters/sec experiences

a force $F = 10^{-7} \cdot (Qv) \cdot (\frac{2\pi NC}{R})$ newtons or $10^{-7} \cdot (Qv) \cdot (H)$ newtons

Force on short wire, L_1 meters, carrying C_1 amps is $10^{-7}(C_1L_1) \cdot (H)$ newtons

Two short parallel lengths of wire, carrying currents, exert $F = 10^{-7}(C_1L_1)(C_2L_2)/d^2$

---

②

SECTION A. You are advised to spend $1\frac{1}{2}$ hours at most on this section, then proceed to Sections B and C, returning to this part if time permits. In Section A give the answers in the spaces provided (with no explanation unless one is asked for). Do not spend long on a question that seems to be hard, but proceed to the next.

ANSWERS MAY BE LEFT IN FACTORS. Scratch work may be done on the backs of these pages, or on the back pages of answer booklets. It will be ignored in grading this part, except where asked for.

1. (a) 1 kilowatt·hour is a unit of . . . . ______

   Expressed in other, MKS, units (not mentioning watts) its value is ______ . ______

   (b) 1 Mev (1 million electron·volts) is a unit of ______

   Expressed in MKS units its value is ______ . ______ units

   (c) "931 Mev is the equivalent of 1 atomic mass unit" (or "940 Mev is the equivalent of 1.008 atomic mass units, the atomic weight of hydrogen"). Explain in your own wordw what "is the equivalent of" means in the first statement above (of if you prefer interpret its meaning in the second statement).

   ______

   ______

   ______

2. Make a rough numerical estimate of each of the following (calculate out a very rough answer). (See front page for data.)

   (a) The speed of electrons from a gun with gun-voltage 100 volts.

   v = ______ . ______

   (b) A proton and an electron attract each other electrically. They also exert a gravitational attraction on each other. Calculate the ratio of their electrical attraction to their gravitational attraction. (gravitation constant, $G = 6.6 \times 10^{-11}$ newton·meter²/kg²)

   $\frac{F_{electric}}{F_{gravitation}}$ = ______

   (c) The ratio of mass of proton with kinetic energy 3 Bev (billion electron·volts) to the mass of a proton at rest.

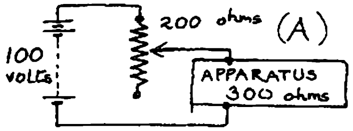
   $\frac{M}{M_o}$ = ______

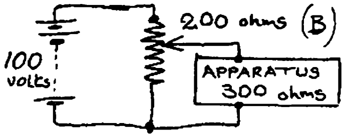
   (d) The fraction of a stockpile of a radioactive element with half life 6 minutes, that would be left one hour later. ______

OVER

③

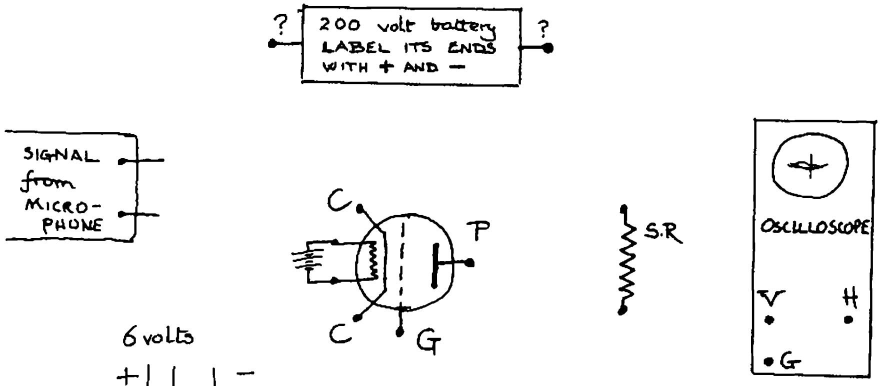
3. (a) Two students wish to use a rheostat (maximum 200 ohms) to obtain a variable p.d. which they will apply to some apparatus of resistance 300 ohms.





The sketches (A) and (B) show the arrangements used by student A and student B . Which student will be able to achieve the greater range of voltages and what will be his range? Give clear, explicit reasons for your answers.

(b) A small alternating voltage, derived from a microphone listening to a musical instrument, is to be amplified and then viewed with an oscilloscope. Complete the connections on the diagram below. Assume that the triode that is to be used operates best with its grid biased at 2 volts negative. Use 200 volts for the plate circuit. Mark + and - signs on the 200-volt battery.



(S.R = Sampling resistor)

over

④

4. A small nuclear reactor, using ordinary uranium (mixture of U^{238} and U^{235}) and carbon moderator is cooled by a huge stream of water pumped from the local river. Cooling water flows through the reactor at a rate 600 kilograms per second. It goes in at 20° and emerges at 55°C.

(a) The heat carried away per second is ____________ ______ UNITS

(b) What event in the reactor produces this heat? ____________

(c) If this heat should be used to drive an electric generator, with overall efficiency 20%, the electrical power produced would be about . . . . . . ____________ kilowatts

(d) Why is this heat usually thrown away into the river instead of being used for power? ____________

(e) Suppose liquid sodium, of specific heat 0.25 is used as coolant instead of water, and the same mass, 600 kg flows through per second. The temperature rise would be. . . . . ____________ C°.

(f) A nuclear reactor is always built with a thick shield of special concrete around it. What dangers are feared, and what should the shield be made of to guard against them? ____________

(g) There is a "critical size" for any given type of reactor. Why does a reactor that is smaller than that fail to run? ____________

(h) Suggest one or more ways of modifying a uranium/carbon reactor's design to make the critical size smaller. ____________

over

5. A satellite moves in an orbit that ranges from 500 miles above the Earth's surface to 2000 miles. Without any reference to Kepler's laws, give a clear argument to show that the satellite must be moving faster when at 500 than when at 2000. ⑤

6. A "gun" is set up to accelerate positively charged particles with an accelerating potential difference of V volts.
When the gun is used to accelerate protons they emerge with speed v_p
When it is used to accelerate α-particles, He^{++}, they emerge with speed v_α

(a) The ratio, v_α/v_p , will be . . . .

(b) Why is your answer to (a) independent of gun-voltage V ?

(c) For very large gun voltages the measured ratio would be slightly different from your prediction in (a). Suggest a reason.

(d) For extremely large voltages, the measured ratio is nearly 1.000 Explain.

(e) If streams of particles emerging from the gun are shot across a magnetic field (at right angles) the radii of the orbits for alpha particles and for protons, from the same gun-voltage V, will have the ratio R_α/R_p =

(To avoid losing all credit through a careless mistake you should show your working in the space below. You need not explain it.)

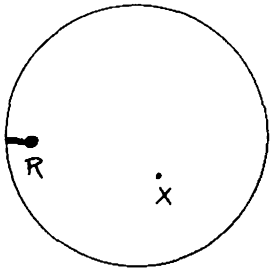
OVER

7. (a) What kinds of particles make tracks in cloud chambers? ⑥

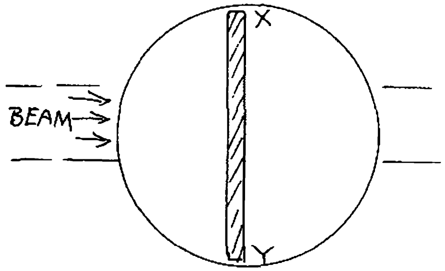
(b) What particles make no tracks themselves; and why?

(c) The bottom of a cloud chamber containing air is a moveable piston consisting of water. The piston is suddenly lowered so that the air above it expands. Explain briefly how an alpha particle that shoots through the air can then make a visible track.

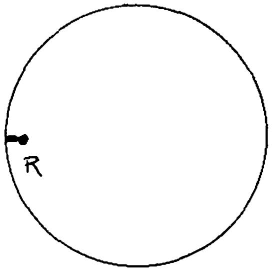
(d) In each circle below sketch the cloud chamber tracks that you would expect.



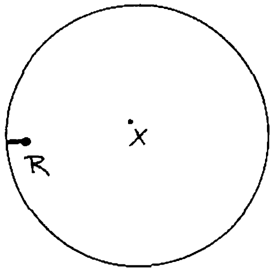
Sheaf of alpha particles from radium at R . One of them Collides with oxygen atom at X .



A beam of neutrons passes through chamber from left to right in region shown. X Y is a thin sheet of paraffin wax (made of carbon and hydrogen). Chamber is filled with air and water vapor.



A slow beta ray ejected from radioactive atom at R .



α-particle from R collides with helium atom at X . Emphasize any special characteristics.

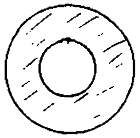
OVER

8 QUESTIONS ON THEORY OF MAGNETISM.

⑦

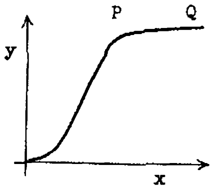
In the light of a simple theory of magnetism, comment on or answer each of the following, using a diagram where helpful.

(i) A man thinks he has magnetized a steel ring, but finds no poles. Is it possible that in any reasonable sense of the word it is magnetized? (EXPLAIN)



(ii) How could you test your explanation?

(iii) The sketch opposite shows a graph of the magnetisation of an iron bar (using D.C., not A.C.).



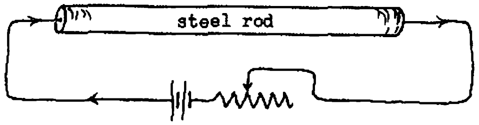
(a) Interpret the stage shown by the nearly horizontal part of the curve, PQ ?

(b) What is (probably) being plotted upward on this graph, that is, on y axis?

(c) What is (probably) being plotted along on this graph (that is, along x axis)?

(iv) (HARD. Make an intelligent guess.) A student, asked how to magnetize a solid rod of steel, replied mistakenly: "I would use a battery to drive a current through the bar, as shown in sketch."

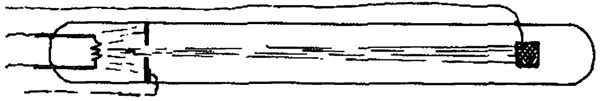
What magnetisation, if any, do you think this treatment would produce?



OVER

9. A physicist wishes to heat a small cube of tungsten white hot in a vacuum. He does this by bombarding it with electrons.

⑧

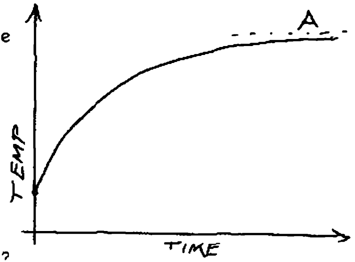


Electrons from a hot cathode are accelerated by a p.d. of 400 volts between that cathode and the cube. 10^{19} electrons reach the cube in each second.

(a) the current from cathode to cube is . . . . . . amps.

(b) the rate at which energy is being delivered to the cube by the electron stream is units

(c) When the bombardment starts, with the cube cold, the cube's temperature begins to rise steadily; then it rises more slowly; then it rises more slowly; then it approaches a constant temperature "A", as sketched on the graph. At the stage of constant temperature "A", where does the energy delivered by the electron stream go to; and why does the temperature stay constant?



(d) The physicist changes his design. He replaces the cube by a larger tungsten cube of twice the linear dimensions, and wishes to heat it to the same final temperature "A". He uses the same heated cathode, supplying 10^{19} electrons per second, but changes the accelerating p.d. to obtain the same final temperature.

What p.d. should he now use? . . . . volts

Explain why

(e) (HARD) With the original cube, the temperature started rising 160 C° per second when the bombardment started. With the larger cube, of double side, the temperature should start rising, at first C° per second.

OVER

SECTIONS B and C: Please write your answers to Sections B and C in an examination booklet.

(9)

SECTION B: ANSWER ONE OF THE FOLLOWING, EITHER B.1. or B.2.
You are advised to spend 20 to 30 minutes on it.

B.1. Give a "theoretical argument" discussing various bodies in a furnace, to show why you would expect a good absorber of radiation to be a good radiator (emitter) and a good reflector to be a poor radiator.

(Since the result is given, it is the argument that is needed here: a clear statement of assumptions and setting forth of logic.)

B.2. Suppose another student has followed this course with you but has missed completely any reading, classes, etc., that deal with the mass-spectrograph. Write an account of it for him. Explain what it is for and why its measurements are important. Then explain to him carefully the working of the instrument to which the following lecture notes refer:

> "Mass-spectrograph. Sample containing material to be investigated fed in, in the form of gas, ionised by electron bombardment, accelerated by electric field, bent with circular focussing by magnetic field, H, collected, charge carried to electroscope. Different isotopes collected and measured by changing the voltage."

Radius of circle given by $r = \dfrac{\sqrt{2\ V\ m/e}}{10^{-7}\ H}$

(Assume that this note is in itself too hard and incomprehensible for your neighbor. Expand it and explain it, with diagrams wherever they can help. Show carefully how the expression for r is derived --- see front page for basic formula list.)

OVER

SECTION C: Answer any two of the following three questions, C.1., C.2., C.3. (10)
(You are advised to spend about 30 minutes on each of your two answers.)

C.1. Choose any two of the following "tools of physics" and, for each, (a) describe its working carefully; (b) say what it is used for

- (i) Geiger counter (omitting details of power supply, amplifier)
- (ii) Cyclotron (including, if possible, algebra)
- (iii) Linear accelerator (indicate geometry)
- (iv) Nuclear reactor

C.2. What, in your opinion, are the goals and methods of theoretical physics? Illustrate your answer by discussing one or more examples, such as:

- Rutherford atom picture
- Simple magnetic theory
- Kinetic theory of gases
- Relativity
- Quantum theory

(Choose other examples if you like, from physics.)

C.3. Show that a simple kinetic theory of gases leads to the prediction (PRESSURE)(VOLUME)=(1/3)(No. of molecules)(mass of molecule)(av. speed). State your assumptions clearly, and explain your reasoning briefly. Describe briefly the measurements you would make to obtain an estimate of molecular speed with the help of the expression above.

SECTION (VIII). LABORATORY WORK

(See also the comments on Laboratory near the end of Section (IV). For the sake of completeness, some of the earlier comments are repeated in this Section.)

Laboratory work can make or mar a student's understanding of science. In my own course, we have laboratory every week (3 hours); we encourage students to learn by doing their own experimenting — and enjoy that. And we give them time for that by letting some experiments extend over several weeks. Thus, students do fewer experiments, with less instructions, and have some chance to be a "scientist for the day."

What do Good Labs Need?

For the present discussion, I shall call such labs "good labs".* Good labs make some special demands. They DO need:

(A) time for students to do their own experimenting, to learn by mistakes instead of following a series of warnings or instructions.

(B) time for students to finish their experiments. (Please stop pulling every experiment up with a jerk at the end of one session.)

(C) flexibility of time, so that a slower student can finish his experiment the next week, while a faster one branches out on a sideline or starts a new experiment.

(D) importance for each experiment: this is fostered by giving the student good apparatus and all the time he needs. Importance often grows exponentially with time.

(E) time for discussion and criticism, after the experiment.

All these needs compel us to do fewer experiments. Then we can spend three weeks on an "open" investigation of springs, three or four weeks on the simple pendulum, a week measuring the motion of an accelerating wheel and a week discussing results. "That will make some students lazy," say the critics. I reply, "(i) I don't believe it: such students will be lazy anyway, and I do not mind if it comes out in the open; (ii) I don't mind if it does: enforced activity breeds few long-term gains; (iii) I have tried the slower timetable and I find the results well worth any such costs — try it yourself and then judge."

(F) instructors who will run the labs with their heart in trying the new method. (I feel ashamed to have to mention this criterion.)

(G) some senior faculty staff to set the example and help train new instructors.

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* My own labs range from "open labs (see page 63) to some standard teaching-lab experiments. The term "good labs" extends even wider. It is intended to cover all labs that serve the present aims, including the much grander form of open labs which are now being named "free labs," "open-ended labs," "free-wheelers." Those latter will indeed be good labs — so long as they are not swamped by elaborate equipment or sidetracked into engineering gadgetry — but I consider them too expensive in equipment and staff time for a large group.

(Instructors leave the department; and new ones arrive full of enthusiasm, but, if put in charge of labs, they tend to develop long instruction-sheets and provide carefully prepared apparatus, and hurry students through the experiment to a formal report* – and then we are back where we started.)

As usual with educational changes, there are rumors of other needs that are not real. Some are listed below:

(a) A good laboratory does NOT need special apparatus. (Traditional equipment can be put to the right use by a change of attitude and a lessening of cookbook instructions.)

(b) A good laboratory does NOT need expensive apparatus (e.g., a complete X-ray outfit. This may bring glamour or even genuine interest and employment but it also brings its own booklet of instructions. When preparation for lab requires hours of reading or formula-making beforehand, or when the lab itself has to follow long instructions in a hurry, the experimental work is likely to become debased – in students' opinion if not in fact – into a form of minor engineering.)

(c) A good lab does NOT need very modern apparatus.(It is fashionable to say labs are poor if students study springs instead of measuring the quantum-constant. I agree that modern experiments are important and attractive, but I cannot join in the hypnotic condemnation of all else. Instead, I hope we shall treat modern experiments with the same intelligent censorship as all others: avoid those with high ratio of spoon-fed instructions to student activity; welcome those which students can do, and understand, themselves. There is danger here of confusing what students do in lab with what students should see in modern physics, whether in lab or in lecture or films).

(d) A good lab does NOT need extra time (it just does fewer experiments in the year).

(e) A good lab does NOT need extra members of staff: far from it, the staff live a quiet life, using their brains and feet more and their voice less. So we need less staff rather than more, although we do need good physicists and keen ones. Where a critic objects that his own institution is too large for my kind of labs, I ask why simple proportionality** between staff and students does not hold! I know that in fact he does not lack staff but willingness.

(f) A good lab does NOT need special instructors or an evangelist to keep it going. It needs a whole faculty's good will; but, given that, it does not need peculiar aptitude or long training. Instructors and other staff learn in a few months at most to run labs like mine. (At this point, the discussion takes a personal turn, but I feel it is necessary. Colleagues at other institutions, asking about my own course's lab or visiting that lab, are apt to say, "Yes, but that is a peculiar scheme that only you can run." They might just as well say that a happy family is a peculiar group that only one or two parents in a thousand can run.) I find that if I take the trouble to discuss both policy and arrangements in detail with my instructor-colleagues beforehand, they then run their own lab sessions with admirable skill and success: good timing, quiet attitude, and students working as adults at

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[*] I have watched, with grieving horror, colleagues in a neighboring course adopt some "open" experiment from my lab, reorganize it "efficiently" and put it to complete misuse by crowding three weeks of the students' own experimenting into a single thoroughly instructed afternoon.

[**] One critic even objected that he could not run labs like mine because he had three times as many students. While I was wondering whether to raise the proportionality idea, he went on to explain that each student came to lab only one week in every three!

experiments. Physicists are certainly bright enough to learn new techniques and attitudes; and when they find their labs bring less trouble to them and more success to students they will continue.

Furthermore I find by trying it that a young Instructor – once he has adopted the scheme and tried a complete year of it – can replace me and take full charge – for a year at least. I was away for a whole year, and the labs were run by an instructor who had taught in lab with me for a full year. Returning on visits I found him and a staff of 8 running labs with full success. True, he probably needed, and certainly had, the full backing of his chairman. (However, I fear such labs would hardly persist for years without some guiding influence from senior staff.)

Moreover, I find that a young Instructor can carry the full flavor of these labs away with him to another institution, and maintain it and extend it there. But he has to keep on doing some of the lab teaching himself, and he probably needs – and certainly had in the case I quote – the full backing of his President.

The Running of a Laboratory Program

I choose my lab instructors carefully, talk with them about aims and methods, run one lab each week myself (with many colleagues there, ostensibly teaching, but really as visitors) in which I try to give students plenty of apparatus and encouragement but very little spoonfeeding help. We require only brief records, written in the lab not a filling in of forms or a dutiful writing out of long discussions; and we insist that we have no use for childish lists of apparatus or dutiful recopied records. We want something more like a research scientist's current records.

Departmental Arrangements

Those of us who mind about labs can train staff to run good labs. The training – which means giving ideas and techniques rather than producing new experiments – takes months not years. We have to choose staff with ability and interest; and there we need strong backing, and some good example, from departmental authorities. Otherwise the forces of habit and economy will wreck any attempt, and it would be better to have no lab. So, a department needs to decide whether laboratory work is worth a genuine effort by the senior teaching staff. Many a young physicist has strong views on elementary teaching. He arrives keen to give lectures (failing some more advanced course); ready to teach classes as a chore; but openly despising laboratory teaching. However, he is flexible and if he finds his department considers lab very important he will make a good start.

Of course it is not necessary to have someone of faculty rank in every lab; of course some Graduate Assistants are better in lab than some professors. But if all, or even many, labs are entrusted to Graduate Assistants it is hard to maintain the flavor we want, since assistants are new and young and bring prejudices from other labs – they need an active example to follow. More serious still: all concerned are apt to draw the conclusion that labs are unimportant, just chores for junior staff – and then we are back where we started. So some laboratory teaching by department faculty seems practically essential.

If you are a senior physicist, hesitate before you object to this picture: reflect that you too will willingly give lectures; then ask yourself whether you consider labs important enough for you to take a small share of their teaching. They are vital, and they need your direction, your teaching-help, and your good example. They are not demanding: all you have to do is be a good physicist and keep quiet. An afternoon in lab takes less time and energy than preparing and giving a single lecture.

Discussion with Instructors and Students

I discuss the aims of labs with both instructors and students; and I visit each lab group early in the year to give students a short talk on transfer of training (along the lines sketched on pages 62-63) ending with the hope that "you will make yourself a scientist for the day." I explain frankly that experiments (of Kruglak and others) have shown that labs do no better than a class in teaching facts and principles of physics, and problem-solving skills - and labs cost far more in time and money. We do not use labs (primarily) for that; nor do we think our students so stodgy that they understand only what they see and smell and touch. What we do expect from labs is a deeper and more lasting understanding of science, gained by working with one's own apparatus, by experiencing the frustrations and successes of experimenting, the delights and sorrows of a scientist. For understanding the interplay of experiment and theory, nothing can replace, for many students, the doing and discussing of their own experiments. And for all of us, delight comes strongest from the experiments we do ourselves. To sum up: this is where the student makes contact with adult science.* For an over-all recommendation, I point to the analogy with learning a foreign language: laboratory is the real trip abroad.**

Instructions to Teaching Staff

> "Lab should be a quiet place where students work at their own experiments, make their own decisions, solve their own difficulties as far as possible. Do not forestall mistakes, in some preliminary speech or later; do not explain how an instrument works (unless really necessary); never draw a circuit; and do not even answer a question except by another question. Do offer comments and help where you feel it is necessary. But where a student consults you to avoid doing his own thinking or making his own decision, try to answer by asking a question or by offering the true comment 'It's your experiment.' So please try to keep silent; but use your whole brain to solve the intellectual problem of devising stimulating questions and encouraging comments as one research man to another."

(See the remarks on Laboratory, with special attention to Graduate Assistants, near the end of Section (IV) of this booklet.)

Laboratory Reports

We ask students to keep a record in a notebook (see page 64 for comments). It is part of our teaching duty to read and grade these lab reports. That demands a lot of time, but it is worth it. It is where we as scientists talk to our students as younger scientists. Deciding on a grade should not take more that 10% of the total marking time;

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* In talking with ex-students, long after my course, I often raise the question of "lab" versus "no lab" for a future generation. I point out that lab is very expensive in manpower (over 40% of the cost per student) and I ask their advice. They say that the lab took time, gave them hard work, was some of it boring, some of it interesting. They differ over the last descriptions; but to a man they insist that we should keep lab. I ask why. The reply is fervent and clear, though they can seldom explain it. "It would not do to leave it out."

** And, like any intelligent travel-agency, we should give our tourists a good chance to gain lasting experience, rather than shield them from trouble while they travel too fast.

the rest should go to making careful constructive comments. I explain to our Graduate Assistants, who do most of the report marking, that we require only informal reports:

> "... not the formal reports you remember from your own training; but a rough, fairly neat, notebook, like the one you expect to find in your neighbor's research room. Yet the reading of our students' notebooks is important teaching, a major part of your teaching duty. You will be asked to spend considerable time reading them and making comments (and adding a quickly guessed grade). In doing that, remember that they are written by people who are not future engineers being trained, but non-scientists who need to enjoy science now.
>
> Give lavish praise to critical comments, imagination, careful experimenting, justifiable inferences, and above all to a sense of enjoying the experiment. Do not worry much about neatness and spelling – if a dozen years of school have failed, it is too late for us to begin. Do not harp on technical discussions that will have no later use. Do not require long descriptions of procedure or lists of apparatus – even a moron reader could infer those from the student's recorded measurements and you should pose as a fellow scientist, not a moron.
>
> Offer constructive comments where you can: suggest further interpretation or extensions of the experiment; suggest shelving some results until more knowledge enables the owner to put them to further use.
>
> Among brief comments, the most powerful is 'GOOD' or 'WISE'; the most valuable is '?' or 'ARE YOU SURE?' The negative ones such as 'X', 'BAD', 'CARELESS' must be given honestly when they are deserved, but they bear poor fruit. For many a weak or lazy job I prefer the blackmailing encouragement 'THIS DOES NOT DO YOU JUSTICE.'
>
> The notebook should be a student's own diary, a record he will keep; so it deserves careful, appreciative treatment at our hands."

Program Notes

To all who teach in labs in my course, I issue a strong invitation to visit my own first-lab-of-the-week on Monday, but I also issue a weekly program* summarizing lab discussions and expected time schedule, etc. There would be little point in printing a full set of those program sheets here, since they depend on details of apparatus, they vary greatly in fullness from a brief note to a long story, and they are supplemented by casual discussions in corridors. A few are offered in the notes below as rough samples of the way our labs are run. The synopsis at the end of this booklet shows our choice of experiments for labs, and their time schedule; but I insist strongly that any experiment, any apparatus will do, if turned in the right direction.

NOTES ON SOME LABORATORY EXPERIMENTS

(Commentary in " " gives samples of the instructor's discussion in conferences, greatly shortened by using dots (...) to show where omissions occur. Student replies – by far the most important part of the conferences – are usually omitted here.)

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* A weekly staff meeting for laboratory would be much better, but for scheduling difficulties. Joining my Monday lab is better still.

"OPEN LAB: INVESTIGATING FALLING BODIES AND PROJECTILES (See Expt. A, page 64.)

In my course, I have this lab for one week only, the first week in the term, when the course has barely begun. In prospect it looks discouraging: too easy, too childish, too quick, and probably too noisy. In fact, it does well (and noisily) and proves really valuable. It sets the style for new Instructors, and it gives students a good start. (Late in the term, in a problem or a test question, some students refer to this lab as the best, where they first saw what experimental work could mean.) It does not lead to trouble over dignity or over accuracy in later labs.

At the start, we explain that the field is to be interpreted very widely: we will welcome any investigation that could possibly be said to involve falling bodies or projectiles. We say we hope for ingenuity in devising an experiment and in extracting some result from it. And we offer to fetch any equipment we possibly can. (Before the week starts, I take new instructors on a tour of stockrooms, stores, equipment in other labs, etc. I warn them: "When a student asks for some apparatus, I never say no straight away. I ask myself carefully whether I can possibly get it, and I do if I can. Please hesitate before you say no. On the other hand, it may be quite wise to ask what the equipment is for. If the use is frivolous I discourage it; but if the plan is serious, I try to get the apparatus even if it does not seem to me suitable or likely to succeed. If I express doubt or suggest a better device, I may do more harm than good.")

We say to students at the start:

> "Keep a record of what you do, or see or find out, but make it very short, only a few lines. Write it with one hand while you experiment with the other, and do not spend time on giving details of apparatus; but concentrate on results. Do not re-copy for neatness."

For a long time little happens except some obvious simple experiments. But we wait patiently (I warn new staff: "Do not be discouraged by the lull; do not try to accelerate students through it by suggestions or enthusiasm"). Then demands grow exponentially: I find students measuring a long fall, dropping balls in a tall jar of water, mapping a parabola, clocking a fast bullet, working on projectile ranges*, using rough laboratory seats as inclined planes, – mostly with genuine enjoyment and little knowledge. (If you don't believe me, try this lab – but please see it right through the full afternoon.) A more adventurous student proposes to drop a bucket of water when there is a hole in the bottom: we encourage him, and provide a camera. Another pair of students build a contraption for observing free fall in an accelerating frame of reference – and they are encouraged to continue for weeks.

There are always some who ask for a "vacuum." We gather all such applicants together and take them to the glassblower. He makes a suitable tube while they watch, and he argues toughly with them about what they plan to put in and when. (We avoid the cookbookish atmosphere of a ready-made tube.)

We give some help by having a suggestive cafeteria table at the side, with balls and blocks of many sizes and materials, pieces of plastic foam (very useful), balances and weights, pipes, rods, string, etc., etc. If a student insists that he cannot think of anything sensible to try (very rare), instructors give him a sheet of paper, show him how to "streamline" it, as in Fig. 9-30 on page 167 and say, "See what you can find out along these lines."

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* We have a number of small metal popguns that shoot a half-inch steel ball out (about 8 ft/sec) at various measured elevations. A toy-shop can provide good substitutes.

In general, we make few suggestions, and still fewer criticisms or explanations. (But we do give praise: we are the hosts in this lab; and our guests are young and new.) Occasionally an explanation is needed to untangle dismay. When a student finds that a large ball runs down a hill faster than a small one, I do not get into a discussion of air resistance with him — that would turn the lab into a lecture — but if his hill is rough I may describe rolling friction in non-technical terms.

If a student gets worried because a small ball runs faster down a hill than a big one, I look at his hill, and if it is a rough knobby one I coax him into thinking about hop-skip-and-jump motions over the knobs, so that the small ball misses some rolling motion.

It might be worth while to continue this lab for several weeks, but I find one day suffices for most. However, we spend the first half hour of next week's lab in a rapid Council Meeting where each student says quickly what he tried and what, if anything, he found or inferred. (Try this: it is not tedious — even the Instructor has to keep on his toes with comments — and it is not wasteful, because it sets the tone.)

ROLLING WHEEL: Investigation of Accelerated Motion (Expt. C, page 65.)

This is an investigation in which the apparatus and the problem are already defined: its creative value lies in its call for skillful techniques and precise measurements and in students' delight in the clear simplicity of the result.

In our laboratory, the wheel and axle are of steel, very carefully turned and ground and then balanced. The rails are of mild steel re-ground flat whenever necessary. The meter-stick is clipped on at a random distance downhill — and students are left to discover this trouble and remedy it.

At the beginning students are warned that the wheel is easily damaged; and they are asked to investigate the relationship between time and distance from rest; but they are given no other instructions — they are simply encouraged to try making precise measurements. After 20 minutes we hold a "Research Council" meeting to discuss techniques:

> "Now that you have tried timing the run for some chosen distance, what advice do you have for your neighbors for accurate measurements? Compare suggestions now, then make a series of good measurements for, say .1, .2, .4, ... meter. What advice? 'Start the wheel carefully': how do you mean?... but isn't there a danger of your finger giving it a forward or backward spin?... 'Safer to use the stick?'...Yes, do take it away sharply. Why does the start matter so much anyway?" [Unless there is a good answer the instructor points out that the early stages take a big fraction of the travel-time — "the wheel loiters about at the start, so that is critical."]..."Other comments? ... Oh; move the meter stick to start at zero. Who noticed that?... Which did you judge by, for start and finish: axle-center, axle-edge, or wheel-edge? Which is best?... Other comments?... You favored watching the wheel and running the clock yourself. Who else did that?... And who used a cooperative scheme: partner running the clock?... Which is better? Why? I have my own opinion — and so would most professional scientists — but you and your partner must make your own choice, or else test both methods. Other comments?... Yes, you need to get ready to stop the clock. But I saw some people who seemed too hasty: they turned away just as they stopped the clock." [Then: short discussion to elicit or expand the technique of 'following through' as

the wheel rolls past the end-point.] "Moreover, there is a fine chance for one or both partners to criticise the decision. What should you do if you and your partner decide the clock was stopped too early or too late?... Record it and cross it out? Why record it at all? Don't even look at the clock if you know it is wrong. One last question: how far can you trust your apparatus? Who took the trouble to listen to his watch?... If it ticks 2½ times a second, can you trust it to 1/10 second?... Who checked his watch against the electric clock on the wall?"

Then students spend the rest of the afternoon making timings – recording all except those that are condemned as inaccurate before they are read.

Near the end, we give a talk on graph-plotting (see page 202) and ask everyone to plot graphs of (s versus t) and (s versus t^2) before the next lab.

At the start of next week's lab we hang a "picture gallery" of all the (s versus t) graphs on a wire stretched across the lab; and the instructor walks along them commenting critically – on information-value and choice of scales, as well as neatness. He points out the value of a collection of many graphs. We provide threads and rulers for choosing and drawing a best-straight-line on the second graph. We hang a "picture gallery" of them, and say with delight "Galileo would be happy." Then we hold a critical conference on the interpretation of the straight-line graphs, starting with the essential question, "Which do you consider true, the line or the plotted points?" We accept many different replies, usually asking "Why" after each. Then the instructor gives a short description of types of graphs, along the lines of the text pages 242, 243. (Examples: Indicative graph, a nurse's temperature-chart; imperative, a temperature-defining line for a gas thermometer, Fig 27-10.) He asks what the purpose or use of this graph, (s versus t^2), is. Although he accepts many replies, he then suggests that "the points are true; they are the facts, as recorded." Again he asks, "Then what does the line represent?" Discussing the answers to that is a very important piece of teaching. Just announcing a single "right" answer impatiently will do harm. Only after eliciting answers from everyone and discussing them does the instructor give his own vote for the straight line here being an interrogative graph, a question-asking line. Even then, the underlying idea has to be reviewed (and discussed all over again next week for some students): that the linear relation between s and t^2 follows by unassailable logic from an assumption of constant acceleration; and that the drawing of the graph-line represents the asking of a question about the points, and therefore a question about the motion of the rolling wheel. (See page 29, last paragraph of text.)

After that, students are asked to insert their graphs in notebooks and add a conclusion – some general inference from their experiment. When instructors read these records they accept various informal wordings of conclusions but not one that says "Our experiment proved that $s \propto t^2$ for constant acceleration." We prefer, of course, a conclusion that discusses likely errors and says "Since my best straight line through the origin.... I consider that my wheel's motion was consistent with ... and therefore with...."

We try to safeguard the delight of that final answer from being spoiled by tedious repetition or by imposed conclusions. A student's conclusion that reads "Nature is simple: my wheel rolled almost exactly with constant acceleration" is worth a great deal; and it is easily spoiled by an instructor's request to "go back and time the 80-cm run again till you get accurate values that agree with the rest." Or, still worse, it is utterly perverted, in its value for a student's growth in understanding, if it is replaced by a dictated, correct, formal conclusion.

On the other hand, once the report is written, we criticise it sternly. If measurements are scattered and inconsistent, we ask "Do these do you justice?" If one or two graph-points deviate far from the general run of the rest, we ask, "Do you trust these? Do they do justice to your wheel? If not, why not?" Above all, we can encourage, by our comment and admiration, the student's own delight in the simple law in his second graph and in the revealing power of its question-asking line.

SPRINGS EXPERIMENT (See page 65 of text.)

At the beginning of the first lab on springs, (or near the end of the preceding lab) we give only brief instructions – the wording is given under Expt. B on page 65. We continue with emphasis,

> "Your own experiment is an open choice for you. Use imagination and ingenuity. We will do our best to provide any equipment you ask for."

Then we hand out pre-stretched spiral springs of steel piano-wire. Students may have as many of these as they want; and a cafeteria on a side-table offers springs of other sizes and materials.

For the "official" spring we buy close-wound springs (about 25 turns, 5/8 inch coil-diameter, to stretch 5 to 10 cms per 100 grams load). We buy them from a local springmaker for about 5 cents each (3 cents in large quantities). We bend up one or two turns at each end to make a loop, and add silver-solder to prevent the loop from uncoiling. Then we pre-stretch each spring by loading it with, say, 700 grams, so that when a student receives an unloaded spring its coils are already separated. He finds it obeys Hooke's Law up to 700 grams load; and it shows very interesting changes after that. We provide loads up to 4000 grams; and we reproach students who stop at 800 grams, saying their spring has "gone wrong." This remark is often a symptom of a narrow view of science generated by over-efficient tutoring at school.

(In the second week of springs we sometimes offer a small swivel and pointer – a piece of lucite with a hairline scratch – and a mirror to clip on to the scale; then students who wish may repeat the "official experiment" more precisely – and some may find that real springs show strange deviations.)

Meanwhile our staff are fetching bunsen burners, stopwatches, a cathetometer, liquid air, thermocouple and galvanometer, a device for winding springs of copper wire, ... etc., etc.

Instructors also move around the lab giving encouragement and praise, making occasional suggestions, asking questions, but seldom showing students how to do their experiment or revealing "the proper way." However, in most labs real activity does not develop at first. There is a depressing lull – so that we all despair – in the middle of the first afternoon of springs. Then ideas grow and demands appear, quite late in that period. By the next week nearly all students are busy with their own investigations.

For the few who claim they are too unimaginative, we provide, as a second-class alternative, apparatus for investigations like Fig. 5-3 (page 79) – and this also serves as a hint to the lazy that the afternoon is to be spent on some kind of experimenting.

Many students could continue with springs for a third afternoon but most have reached a reasonable stopping point. So we bring the springs experiment to a close then with a conference on results on the third afternoon. This conference seems tedious to every instructor until he sees the sense of achievement it produces. It demands utmost patience to carry the question to every member of the group and not stop when half-way around; but it is essential to give everyone his turn. In the conference, the instructor asks each student to say what he did — and then cuts the reply as short as possible — then to say what he found, discovered, concluded, inferred, or extracted from his experiment. In that, the instructor helps to draw out a scientific answer by giving encouragement, asking leading questions, offering technical terms; and he sometimes offers comments on applications of the result or suggests extensions.

For example, to a student who investigated the creep of an overloaded spring:

> "Yes, but it did creep slower and slower. I wonder what that says about the mechanism of creep? Slipping of layers of atoms would just continue...? The changes of crystal arrangement must be complicated. Can you extract any rule for the change of speed with time?... Well, keep your record in case you find a way of attacking it later."

To a student who found a spring stiffer when cooled:

> "Much stiffer?... Still, that might be important for some instruments. Suppose the hairspring of a watch changes like that. Would the watch run faster or slower on a colder day? Of course the hairspring's bronze may be different."

To everyone, when a student has timed oscillations of a spring with various loads, but has not noticed the isochronous property:

> "Incidentally, he made a serious assumption when he timed those bouncing motions — you did time 10 or 20 bounces in a batch didn't you? Does anyone see his assumption?... Well, wait and you may hit on it later."

To a student who tried magnetizing a spring, got into difficulties, and reached no clear result:

> "I agree you cannot make any inference. But it was worth trying. Watch our research people ending with nothing, time and again. Failure is part of successful experimenting."

This "research-council report conference" takes a lot of time but it need not be done often. For the rolling-wheel experiment a picture gallery of graphs and a short discussion of their interpretation suffices; and this long council is not needed again until the "heat-transfer circus," Expt. F, page 74.

A few students devise an experiment that is so good or so complicated that they want to continue longer. Usually we agree — if they think it worth while, we think so too. They are then declared to be "supersprингers." They may continue for many weeks — best of all until they themselves wish to close down. They are given good grades, in no way penalized for the experiments they miss. We say, "as a superspringer you will learn every bit as much about good experimenting. And as regards the factual results of the experiments you miss, you can find out in five minutes by asking some neighbors what did happen.

PENDULUM INVESTIGATION [EXPT. D, pages 66-68. These notes supplement the account there.] First discussion (5 minutes). Instructor defines period, T; explains this investigation calls for great precision; asks what factors might affect T; starts students measuring T accurately for a long pendulum at, say, 30° amplitude "to gain skill and develop techniques"; but gives no further help.

Students do EXPT. D (0) Preliminary Measurements [page 67].

Discussion group. After, say, 20 min. of EXPT. D (0), Instructor encourages students to give advice for good techniques:

> "...Yes, a whole batch of swings. How many in a batch? ...Why? ...Is that enough if you want to be accurate to 1 in 1000 or 0.1%? The period is about ... and your watch .... So, how many in a batch? Any objection to timing that big number? Yes, you will miscount unless you count aloud .... Good, of course your partner should check you. Any other objections? ... Why do you mind if the amplitude dies down a little? ...well that is the best you can do — yes that is a pity but you had better try a range like 33° to 27°; and remember you did that. Other comments?... Cooperated with partner: you watched the clock while he counted and gave signals. Who did that?... Who chose the other way: did it all himself? Well, what did your partners do?... Need they have waited? We have spare clocks.... Get in the way? Where did you start and stop your timings, at the end of the swing, or as the pendulum swung through the center? Who favors which?"

Instructor asks for a vote, which is best and why. He gives no decision, but says a professional could prefer one of these strongly – and he will not say which. (I find that if we announce the right method the lab gains in accuracy but is apt to degenerate in tone.)]

> "Now for the investigation: Which factor should you try first: amplitude, mass, length? Who sees the logical necessity of trying one particular factor first?..." [If some do, instructor asks them not to give show away but wait while others think. Finally he gives the following hint.] "While you investigate the effects of changing one factor, you want to keep the others fixed. But one of the factors here will change willy-nilly – you can't keep it fixed. Which factor is that?... What must you do?... Yes you should try amplitudes first – you cannot make much of the other till you know how to deal with amplitude-changes which will happen willy-nilly."

Students do EXPT. D (1): Measurements: Period vs. Amplitude, [67].

If a student gets discouraged because at large amplitudes he can time only a few swings, we say, "Never mind; record that as a rough measurement: perhaps Heaven will be kind and get you out of this difficulty. Just go on to smaller amplitudes, timing as carefully as you can." Instructor asks for rough graphs, "plotted as you go," and encourages more and more accurate measurements for smaller angles, down to, say, 20°. Students also plot a rough "blown-up graph" with the small range of T expanded.

Instructor discusses the appearance of the graph with its owner – commenting, but not giving any 'right answer.'

Program of progress through D (1, 2, 3). * From then on, the time-table differs for different students, according to their speed and skill. The following "milestones" mark the progress through several weeks of lab. Whenever a few students have reached a milestone, the Instructor calls them together, comments on their graph or other results, and gives them the ensuing discussion.

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* If this description of milestones and varied progress seems complicated, reflect that the running of such a month-long laboratory program is properly to be learned by trying it through. The next year it is easily played by ear from the first year's experience. The account here is only an attempt to guide the first year's running. This serves to illustrate the importance of experience in the running of labs for a sense of experimenting.

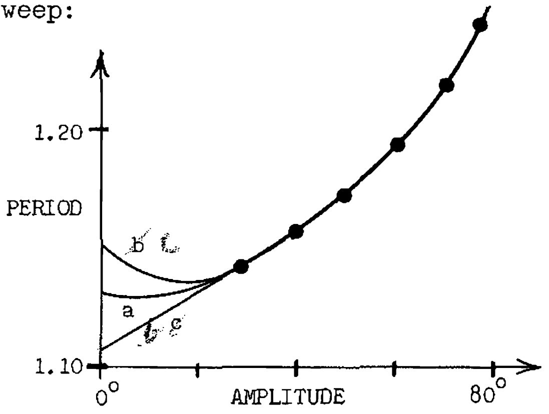
Every lecturer is sure that his lecture will be easier the second time; but many of us fail to realise that laboratory work may gain even more – the whole hope of success – from experienced direction, direction not from outside or above, but in the teaching laboratory itself.

MILESTONE I. UNSATISFACTORY GRAPH, T vs. A. Student brings graph which staggers so irregularly that no definite trend or shape can be seen.

Instructor encourages student to make a fresh start: "Now that you are more experienced... how long would it take you to make a new set of measurements?" Instructor may give hints of better techniques. (If a public picture gallery of graphs is held, students with very irregular graphs will often ask if they may come in another day and make more careful measurements on their own. They do that, and enjoy working quietly and more skillfully among the other day's group of beginners.)

MILESTONE II. SATISFACTORY GRAPH, T vs. A. FOR BIG AMPLITUDES. Student brings graph that shows general form fairly clearly for range 80° to 20°.

Instructor points out that at big angles, 80° to 60°, T changes quite fast. "So that is not the region you want to use for the other investigations. Incidentally, some people complained that those had to be rough measurements. Now you see that all you needed those rough measurements for was to see the general shape of the graph, and to decide that big angles are a poor region for later tests with mass and length – I told you that Heaven might be kind. At smaller angles the graph has shallower slope, but T still changes. That will prevent your other investigations being accurate, unless something different happens at still smaller angles. Otherwise, you might as well give up the mass and length tests, since you do not have a definite enough T to measure. You had better try small angles and hope for a new story. Here [sketching] are three possible continuations, other than a disastrous downward sweep:



(a) It flattens out to a horizontal graph-line near zero like this: wonderful if it does, because then T would be the same for all small angles, and we could use that range.

(b) It becomes a straight line slanting on down like this: we can hire a mathematician to deal with measurements in that case.

(c) It goes down to a minimum and up again, through a bowl like this: then we can use a small range of angles at the bottom of the bowl.

Your hope lies in finding some special form like (a), (b), or (c).

[Instructor avoids showing any preference among a, b, c, and emphasises the present need for some special form.]

The big cardboard protractors we supplied for earlier use are not much use for small angles, so we post a table of tangents of 10°, 8°, ..., 1° and show students how to make a known amplitude by drawing pendulum aside a measured distance.

MILESTONE III. READY TO MAKE TIMINGS FOR SMALL ANGLES, when students and Instructors have gone through the discussion just above.

Students make timings for, say 10°, 8°, 6°, 4°, 2°. (The lone student who asked for a microscope and a tent got them and pursued his test to a fraction of a degree.) (If a student complains he finds it difficult to be sure he is measuring the amplitude correctly – fears he may be using 3° when he records 2° – Instructor says, "Just go ahead. Heaven may be kind.")

MILESTONE IV. FULL GRAPH, T vs. A. [End of D (1), page 67.] Student brings graph for all amplitudes and points out his (rejoicing) conclusion.

Instructor: "Now you know what angle-range you can use for the other investigations. Go ahead, keeping in that range. (Now that you have settled that question, don't open it up all over again.) Time a pendulum with a heavy bob, then with a light bob and the same length from support to center. Better use a long pendulum."

MILESTONE V. READY TO MAKE MEASUREMENTS FOR M and m. [D (2), page 67]. Students make timings and bring their results, often with a puzzled look.

Instructor may ask, "Could you not have predicted this from other knowledge?

MILESTONE VI. READY TO MAKE TIMINGS FOR VARIOUS LENGTHS [End of D (2), start of D (3)]. Instructor explains that this will be a group investigation, to save time. Each student should make very precise timings for at least one length. To give an assortment of data for communal graphs, the first applicant is assigned the range 1.1 to 1.2 meters. "Choose one length anywhere in that range and measure it very accurately." The next applicant: 1.0 to 1.1 and so on down to 0.5 meter. Ranges below that are assigned for a second length, to students who have time. And a few skillful students are given 0.1 or 0.2 meters for a second or third length. Instructor builds a public record of all the measurements and makes sure each student has a copy of the whole collection. The record shows value of L and value of T: and we add value of T^2. Since each student will be using other students' work, we insist on the record also showing initials of observers and number of batches timed and number of swings in batch, thus:

MEASUREMENTS		T^2 (calc'd) sec^2	BATCHES OF SWINGS TIMED	OBSERVERS' INITIALS
L meters	T secs			
1.124	2.122	4.503	100,100 100,50	G. G. & T. B.

(When a printing-machine is available, we write this table on a master sheet with pencil and carbon and print copies in the last few minutes of the lab session.) If Instructor has time, he plots "master graphs" of T vs. L and T^2 vs. L as the results come in. These promote critical comment.

MILESTONE VII. RECORDS READY FOR GRAPHS, T vs. L and T^2 vs. L [page 68]. We usually ask students to plot the graphs at home, following the instructions on page 68. We offer threads and rulers in lab for drawing "best line," at beginning of next lab session.

MILESTONE VIII. GRAPHS PLOTTED AND STRAIGHT LINE DRAWN ON SECOND GRAPH. Instructor announces the relation $T = 2\pi\sqrt{L/g}$. (This is one of the rare cases where we announce a formula. We refer students to pages 172, 173, 178; and we offer to derive it for any who wish.) Instructor asks each student to calculate "g", (i) from slope of graph and (ii) from his own best single measurement. (We point out that this fulfills promise, on page 22, of measuring g by lumping many falls together and "eliminating effects of friction." There was a quibble there: we do not eliminate air friction; but, since it only damps the amplitudes and that hardly affects T, we do eliminate the effect of friction on measurement of g.)

Milestones and progress.*

The first day's lab goes slowly, clogged by lack of skill. We give some encouragement but little assistance. Hurrying students at this stage does not help: it stores up trouble. (But, from Milestone V onward, hurrying is useful and harmless.)

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* See last footnote, two pages back.

By the end of the first pendulum lab, some students will only have reached Milestone I; and they should be ready to start entirely new timings the moment they arrive at next lab. Others will have reached Milestone II or III. They must start on small angles at beginning of next lab. They can either repeat quickly the rough measurements for big angles, or run their new investigation only from 30° to 2°. (Repeating gives a more satisfying result.) Few if any will have reached Milestone IV.

At_end_of second_lab, some will have reached Milestone IV; some, Milestone VI. Instructor gives the talks that follow Milestones II, IV, VI to small groups of students as soon as they reach each of these stages. But, since all students discover the (approximate) isochronous property during this lab, Instructor calls a short general conference on that, preferably with a picture gallery of graphs. He gives the technical name, and points out the importance for timekeeping. (If Ch. 13 is well past, he now gives the answer to Prob. 5, page 222: a clock is needed for longitude reckoning.) Instructor then offers a "theoretical argument," warning that it will be difficult, and goes through the discussion on p.171 in Ch.10; but he does not reveal the answers to (vi) and (vii). He then issues printed copies of that discussion and asks students to try them and bring them to next lab. Or, this theoretical discussion can be postponed a week.**)

In_the_third_lab, all students start at Milestone VI, or get there soon after. This is where we help slower students to catch up, by hurrying them through the mass timings and by assigning them only one length to time – and that may be the length they have already timed for masses!

At_the_end_of third lab some students may be at Milestone VIII, graphs plotted; but many are at Milestone VII, ready to plot. They are asked to take home a list of everyone's measurements and plot graphs. Good mathematicians are asked to calculate g (from slope of Graph II; also from their own best timing for one length); but others wait until next lab.

At_beginning_of fourth_lab, slopes are measured and g values tabulated for the whole group. The student's answers on the problem-sheet of "theoretical discussion" (page 171) are collected and corrected quickly. Then Instructor takes the group to a lecture room and gives demonstrations* of S. H. M. and a general discussion of its properties and uses. (Starting with the moral of the "theoretical discussion," he points out that a load hung on a spring should give similar motion. He shows all the experiments of Figs. 10-3, 10-5, 10-6, 10-7, 10-9, 10-10 (pages 172-175), and the wig-wag machine (page 122), and an oscilloscope with the S. H. M. of the alternating supply's voltage. He discusses the importance of S. H. M. (page 175). How much theory he gives should depend on student's stage and skills; but in general it is better to leave theory to reading and individual conferences; then the group can get back to lab with time for experiments). Back in lab, students are given springs and asked to try any experiments they like, to follow the discussion they have just met. All look for the isochronous property and most try different loads – with surprise. The instructor does not demand an analysis of the T vs. M measurements but lets students treat them as their interest dictates – a spoon-fed instruction at this final stage would be stupid. What a student does with his spring results is often revealing of both skill and character. It is only a rare young scientist who switches at once to Problem 2 of Ch. 7 (the wig-wag, p. 122) and says, "Now I know."*

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* This provides a good opportunity for many Instructors to give a demonstration lecture.

** This "typewritten problem" seems so valuable as an example of argument that I always issue it and I do not grudge the time taken by necessary preparatory discussion in lab.

PRESSURE MEASUREMENTS AND BOYLE'S LAW. [EXPT. E, pages 68-73]

Unless students meet and treat these in good spirit, these are likely to make bad laboratory work: dull, servile, spoon-fed drudgery followed by an insincere "discovery" of a law that has been well-known for three centuries. So we explain frankly:

(i) The "Pressure Measurements" [E (1)] are done solely for practice in preparation for the Boyle's Law experiment, and to provide a measurement of atmospheric pressure needed for Kinetic Theory. (Pre-medicals also need them for direct training.)

(ii) The associated reading on "Laws of Pressure" is offered solely for background where needed, so that we do not spend any time on hydrostatics in the rest of the course.

(iii) (The simple Boyle's Experiment [E (2)] is offered: (a) as a short, interesting historical study, following Boyle's own "laboratory report"; and (b) for you to see in your own experiment a behavior of air that plays an essential part in Molecular Theory, [Ch. 25].)

(iv) The Test of Boyle's Law with Modern Apparatus E (3) makes no pretense that you are "discovering a law." It is offered for you to see for yourself, in precise form, the springy behavior of air that plays an essential part in Molecular Theory [Ch. 25]. This is a test of your experimental skill. The apparatus can yield precise measurements and if you use it carefully you will find the final outcome of your study highly rewarding.

In first week, Instructor gives a short talk about pressure (which has been introduced a week earlier by assignment problems 1, 2, 3, 4, page 69); shows some demonstrations and fills a barometer. [Note method of removing small sticky air bubbles by running a big bubble up and back, as in Fig. 4-10]. Students do all the experiments of EXPERIMENT E (1). [For (1), we provide one or two tall manometers of colored water, 15ft. high, with a clean glass mouthpiece for each student.] We encourage quick calculations, in lab, with slide rules; and we give slide-rule instruction now to all who want it.

In second week we do Boyle's Law, E (2) or E (3) – not both, or there is hurry and confusion. In E (2), Instructor asks students to use Boyle's own account as their instructions – sometimes he reads it aloud first. We provide a J-tube, mercury – weighed out to each student and weighed in again at the end – and a large cardboard tray to catch spillage. If we provide a medicine dropper, that halves the time a student needs! We give no further instructions or help; and many students find the test much harder than they expected. We ask students to include a clear, logical argument in their record. This experiment takes half an afternoon. We sometimes combine it with a simple test of $F = mv^2/R$.

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* One student turned the wig-wag to quite another use. He said, "I want to make sure that it is mass and not weight of the moving system that determines the period. I have the wig-wag oscillating slowly with a large load on its platform. I can remove most of that load's weight, but not its mass, from the platform by having my partner pull the load up with a string, pulling with nearly all the load's weight but not quite. I have trained my partner to move his pulling hand to-and-fro, keeping it above the load, in phase with the motion, to make sure his pull neither helps nor hinders the oscillations. Now we shall time the oscillations with different amounts of weight applied to the platform but always the same mass moving with it. (This experiment of genious was tried some years ago. It has now been recorded – from this source – in a wide-spread text.)

EXPT. E (3) depends on the apparatus available. We spoon-feed students with technical details of our apparatus, so that they can concentrate on precision. [For calculating pressure, we ask students to use the trick suggested on page 72, of adding a "barometer height" of imaginary mercury to the open-side mercury level before substracting the closed-side level. That prevents confusion over + and - signs for the difference of levels.] [This investigation is "timeless": it can be placed anywhere in the course, though it loses some of its point after Ch. 25; so we move it to different places in our schedule to suit other arrangements. If we run short of time it is the first candidate to be omitted completely – and the next would be the original Boyle test, E (2), which would carry Pressure Measurements away with it. Then when we come to Ch. 25 we should say a few words about pressure in class and demonstrate Boyle's Law in lecture.]

CENTRIPETAL FORCE: Test of "Force needed for motion around circle = mv^2/R."

We provide the home made apparatus described at the end of Ch. 21 [page 308] and ask students to use that description as their instructions.* Each pair of students gets one gadget, a stopwatch, a meter stick, and a stand and loads for the static experiment.

> "Try whirling while your partner times you. Then interchange jobs, so that each of you has a record of his own whirling. If the use of the subspring, which is just a signal, is not clear to you, please consult me before you do the experiment."

The latter warning is necessary for a few rash readers – when they ask, we do not issue a spoon-feeding lesson; we just make sure they do read the story.

We ask students to calculate the forces – needed force and actual measured force – in the laboratory and record them on a blackboard. (In this case, calculations taken home turn cold and often come back confused.) We then compute a rough % difference to exhibit the disagreement; and at the end of the day we survey these percentages statistically. To see what to expect, I ask each Instructor who teaches in lab to try this experiment. With our form of apparatus, a skillful operator is likely to emerge with disagreement less than 5%. Between 5% and 10% looks careless. The range between 0 and 5% includes some strong good luck.

This experiment takes little time to do, once students have read the long story; but the slower students take an hour over the calculations. We often combine it with the small Boyle Experiment, E (2).

INVESTIGATION OF HEAT TRANSFER [EXPT. F, pages 72-77].

This is an "open" lab: Expt, F (1) is open and Expts. F (2)-F (9) are open fields for drawing inferences although they have definite statements of what to do. (Expt. F (10) is not a lab experiment but a necessary demonstration.) These experiments are "timeless" and do not even need a lab on heat-measurement as preparation. We spend two weeks on them.

Unless students have read pages 73, 74 very carefully, Instructor starts with a short explanation:

> "In these experiments the field of investigation is Heat Transfer. The experiments are simple, but your main problem is to see how much science you can extract from them, by making logical inferences." [Instructor then describes Conduction, Convection, Radiation, briefly, as on 73, and says these technical terms may be used in recording and interpreting experiments.] "In the first experiment, F (1),

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* Our staff of physicists and technicians suggest many improvements or elaborations; but we find the form described clear to students and well-behaved, and accurate enough for an "experiment principle."

the field is open: try any experiments on the travelling of heat that you can think of. You have a tray of materials. You should ask for other things you want, and we will do our best to provide them. The other experiments have definite instructions, but it is up to you to observe all you can.

In all of these experiments the chief aim is to make inferences – sure ones with good logic, and risky ones by a clever guess – from your own experiments. Treat it as an intellectual game, to squeeze as many conclusions and hints as you can out of your observations. In reading your records we shall give you credit for each inference you draw (with any justification): see how big a score you can pile up."

Instructor then explains what is expected in record, following the "Record and Inferences" paragraph on page 74, and he gives that example of inference from thermometer plunged in hot water – and its warning against reverse logic of "explaining" from other knowledge.

"Today do F (1) and F (2)- F (4). Next week, we shall provide apparatus for F (5)-F (9) and give a demonstration of F (10). You chould also continue F (1) then."

The equipment for F (1) consists of: rods and wires of copper, iron, glass, matches, crystals of "dye," thermometer, a small beaker, tripod (iron), bunsen burner. (Few students realize that the bunsen itself can be investigated.) We expect to provide many other materials when they are asked for. If we are patient and encouraging – but give no other help – some remarkable experiments emerge. If many students do nothing very exciting for F (1), we rely on F (2), etc. to provide enough inferences. F (2) - F (4) do not take long – though inferences from F (2) need considerable thought. If inferences are written in the lab, the record seems thinner but more genuine. F (1) is obviously of indefinite length. If it is crowded into 60 minutes, its yield is too poor to be worth while. Sometimes we let it expand to several hours, and then students must take notebooks home to finish inferences. We have even tried expanding F (1) to several weeks but although the atmosphere was good, only a few students made great advances in the longer time. The success of F (1) depends strongly on the instructors' skill in giving encouragement and making occasional suggestions.

Unlike the mark for other experiments, that for EXPT. F is not a general opinion, but is a score of inferences tallied up at a flat rate. The next page shows my grading suggestions to laboratory teachers.

For experiments F (5) - (9) we have around the lab, several electric cone heaters, kept bright red hot, behind asbestos screens with a hole. (We shorten the wire of a standard element so that it maintains a higher temperature.) Instructor heats up the copper sheet for F (7) from time to time, and administers aluminum leaf for F (8). Students simply follow directions of pages 75, 76. Instructor gives a demonstration lecture with thermopile and spectrum, preferably with quartz optics.

SIMPLE HEAT MEASUREMENTS. We follow Ch. 27 Expts. A, B (demonstration), C(i, iii, iv), E or C(ii).

POWER. We follow Ch. 28 Expts. A(i, ii, iii, v), A(iv), B(i), E, D.

[E is a 3/4 HP D. C. motor with a pulley running against a leather band-brake. D is a cone heater, running on D. C. in distilled water.]

NOTES ON GRADING EXPERIMENT F

As we warned students, these reports should be graded by the inferences, and not by dutiful descriptions or clever essay writing. However, we should also give credit for ingeneous and sensible experiments devised outside the official list, and for special improvements or precautions applied to the official experiments.

The following page gives inferences that we may expect to see, with the credit suggested for each. In grading, start from zero and simply pile up positive credits for actual inferences. This will give some students a very poor grade -- but at least they will receive a clear explanation of the grading scheme at the beginning of next lab. Others may pile up a considerable credit, and they deserve that. As usual, the major benefit of your work with the reports is in the comments -- particularly constructive ones -- that you write. Deciding on a numerical grade should be a minor matter even here; but you will find it helpful to use some uniform scheme of check marks for acceptable inferences that will enable you to add up the grade easily. Give a bonus point for anything that you think deserves it.

In grading my own reports I add comments:

> Where a student gives a clever inference I write strong praise.
>
> Where "heat" or "heat rays" is used for "radiation", I cross out the word "heat", with a clear X .
>
> If "hot water rises" (or hot air), I add "in cold water" ("in cold air"); and I add the criticism, "This is really only an observation."
>
> Where a student misses the important inference that water is a poor conductor, I write, "Any other inference for water?"
>
> Where in F(1) or in F(4) student uses the speeds of heating of the rods or wires, I add comment: "Speeds also involve specific heat and density".
>
> In the rare cases where a student notices the sheath of stationary hot gas around a heated match or wire in the shadow-by-arc, I add: "Good. This is important in the design of gas filled electric lamps".
>
> Where a student tries to EXPLAIN (by knowledge from books, previous course, etc.), instead of pretending ignorance and making INFERENCE, I put a clear X and say: "Missed the point".

The following page lists some inferences. We should welcome others, and reward imagination and reasoning richly.

SUGGESTED PIECEMEAL GRADE-CREDIT FOR SOME INFERENCES

F(1) You must make your own scheme for F(1), using imagination, judgment, a certain amount of sympathy, and some guidance from the list for F(2), etc., below. Here are a few examples:

Glass conducts very poorly compared with metals	1
Glass expands less than Cu when heated (reasoning must be given)	1
Flow of heat along thin wire much less than along thick wire	1
Melting point of copper below M.P. of iron	1
Temp of bunsen flame between M.P. of copper and M.P. of iron	2
Risky but brilliant inference: MFP of dye in water v. small	2

F(2) HEATING TEST-TUBE OF WATER+DYE

Hot water rises. (Correct this by adding "in cold water", and "this is really only an observation")	$\frac{1}{2}$
Hot water weighs less. (Correct this to "is less dense"). . or Hot water is less dense (than cold).	1
Therefore, water expands when heated	2
Heat travels upward (and around) by convection in water. . .	1
Water is a poor conductor of heat.	2
If reasoning for this is given, add bonus.	+2
Glass must be a poor conductor	1
Air must be a poor conductor too	1

F(3) INGENHAUSZ COMPARISON. (Inferences difficult or unlikely, beyond the obvious rough comparison suggested in the instructions)

Different substances conduct differently.	$\frac{1}{2}$	max 1
Order of conductivities is: copper,...,..., etc..	1	
Assuming $k \propto L^2$, these k's are roughly proportional to ...,...,		1

F(4) SHADOW OF FLAME (Inferences difficult:we accept some descriptions)

Hot air rises (or equivalent, or better form).	1
Turbulence starts some way above flame, extends far above. . .	? 1
Inner cone seems different	$\frac{1}{2}$
Inner cone contains raw gas (no credit unless tested).	1
Yellow flame has something that absorbs light.	1
Heated match or wire has stationary sheath of gas around it.	1 or 2

F(5) - F(9) Scored similarly, with special bonuses for inferences concerning: speed of radiation, heating of absorbing glass, logic to rule out possibility that aluminum leaf acts as a bad conductor in F(8)b.

JOULE EXPERIMENTS. We follow Ch. 29 Expt. A for the simple experiment, giving no further instruction. Then we give students a hydraulic brake apparatus, the McLeod-Werbrouck one, described in Amer. Jour. Physics, Vol. 28, 793-796 Dec. 1960. We issue an instruction sheet, and give a short talk, to explain how and why the measured torque F·R applied at the rim of the base-plate of the "calorimeter" is equal to the torque f·r closer to the axis, in the region where the water is churned between the two turbines. And we show that f·2πr·(number of revolutions) is the work that gives the interchange of energy from mechanical form to heat. Then students use the apparatus without further help. This experiment is more spoon-fed than we like, but the apparatus is clear and works well, and we consider that contact with some such experiment is an essential piece of education. As pointed out on page 442, we ask students to do these experiments to gain clearer understanding of Joule's work hoping they will sympathize with his difficulties and admire his skill, rather than succeed in matching his results with special apparatus.

ELECTRIC CIRCUITS. We spend many weeks on a series of experiments, using Ch. 32 for instructions, teaching electric circuits entirely in laboratory with no help from lectures, but considerable help from problems assigned from Ch. 32. Instructor starts first lab by showing how circuits are drawn conventionally [page 506].

> "Even though you arrange your apparatus and wires in an irregular pattern, you should draw your circuit with horizontal and vertical wires like this, and use these symbols. We want you to learn by setting up your own circuits. If you have worked with electric circuits before, join with a partner who has done so too; if not, join with one who has not. Then you can both go at the best speed. If you have done such experiments before, do them very quickly here, to show your skill." [That is a good face-saver for the radio enthusiast who does not know that he needs our simple experiments. Of course, if we find a student really has done electricity thoroughly, we move him on to much more advanced experiments.] "To safeguard our equipment, without spoiling your experimenting, we make a rule that an instructor must see your circuit before you connect it completely to the supply: always leave one binding post of battery or other supply untouched until checked. A check saying 'yes' does not mean your circuit is right, or even safe — it just means we take responsibility. And when we check a circuit of your apparatus, we expect to see it already drawn in your notebook and your partner's. Never mind if you draw a wrong circuit: don't erase; just draw another. Try Experiments A, B, C, D. We are ready to check circuits as soon as you have them."

Later in that first afternoon Instructor sets up the communal demonstration of Fig. 32-22 and shows it quickly — that must not come till all have tried Expt. B and preferably C. Instructor gives a short talk about current, amps, coulombs (still treating the ammeter itself as a black box) and mentions water analogy briefly as an ex post facto illustration.

> "All we know about a current, at this stage — perhaps ever — is what it does: it heats wires, makes magnetic effects nearby, and it can carry copper across in a copper sulfate bath or carry out more complicated chemical changes. We not only recognise it by its effects, we measure it by one or other of those effects. In this course we measure currents by their copper-plating effect. We define 1 amp as the current that carries across 0.000000329 kg of copper per second. We say that a current of 1 amp means that 1 coulomb (whatever that

is) passes any point in the circuit each second. C amps means C coulombs/sec. A coulomb is the chunk of electricity — whatever that is — that moves with 0.000000329 kg of copper in an electro-plating bath. We shall now use that to check some one mark on your ammeter."

Instructor gathers students and their ammeters together and carries out Demonstration Expt. E. We use 10 or 12 amps for 1000 secs, through all the ammeters in series. We include two rheostats, (one, for fine adjustment in parallel with the other), and that gives some students a suggestion for future use. We use the following solution, suggested by the Research Department of The American Brass Company, for consistent plating:

copper sulfate ($CuSo_4 \cdot 5H_2O$)	28 ounces/gallon
sulfuric acid	8 ounces/gallon
chloride	30 ppm.(HCl)
glue	11 ppm.

with current density 25 amps/sq.ft of facing area

Then, without any explanation about voltmeters or P.D., we ask students to try Expts. F (i) and (ii). Note that the wording of F (i) is intentionally vague, almost misleading. We would like students to put the voltmeter in series first. (Students who are proceeding more slowly may leave F (i) and (ii) till next week. Sometimes we do not require Expt. D of all; but then we have to show demonstrations instead). We assign Problems 1*, 2, 3, (4), (5), 6, 7*, 8*, 9, 10, and we assign pages 510-516 as essential preparation for next lab.

Voltmeters.

Next week we make sure everyone has done F (i). Meanwhile, students who are ahead start on G and prepare for H. Then Instructor gives a talk on P.D. (If we are to teach all Chapter 32 by laboratory and problems, there must be some short lectures like this.) Essentially, he repeats the whole discussion of Voltmeters and Voltage, from the end of p. 511 to the end of p. 515, sketching water circuits and building up the idea of energy-transfer per unit volume of water, and then energy-transfer per coulomb of electricity, as useful measures. (Before giving this talk for first time, the Instructor should try Expts. G and H himself, multiply the time he takes by a suitable factor, say 3, to estimate the time students will need. Then he can see how much time he will have for his talk). He explains the reason for Expt. G. We must regard a voltmeter as a black box; so we need an external test. He explains that Expt. H is difficult, long, and not very accurate. It is an essential experiment of principle, rather than an accurate practical calibration.

Students then do G, H. (Students who do not have time to finish H, or who run into difficulty, will probably gain more valuable understanding of electricity if they do H next week instead of an Ohm's Law experiment. Hurrying is not good at this stage. By next week we can cater to various speeds: there are minor experiments for slower students to skip, extra experiments for fast ones). We assign Problems 12-16, 20.

Cafeteria of Equipment.

As students grow familiar with electric-circuit experiments, we place more and more apparatus on side-tables as a "cafeteria": rheostats of various ranges, ammeters and voltmeters of various ranges; spare switches, etc. We expect students to choose a meter with suitable range for their experiment, and to change meters if they think advisable. We do not tell them which meter to use: we blame them if they do not choose or change wisely.

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* Problems 1, 7, 8, are best assigned for the week before electric circuits begin.

Ohm's Law.

In the third week, Instructor collects reports on voltmeters from Expt. H, gives a very short talk on Ohm's work and asks students to start on Expt. I. (We provide loose lengths of constantan wire: we let students overheat it, burn it if they like. If we provided ready-made, nicely insulated coils the experiment would look contrived.) Expts J, K, L, O, P, S, are optional, for students who are moving faster with success.

If one or two do J, K (preferably extending down to low voltages with storage batteries, to show the curve well) their results can be discussed with the whole group. These results for tungsten and carbon are confusing, since students cannot separate out the effect of temperature-changes. Therefore we offer students a small coil of insulated copper wire, and another of constantan, that can be dipped in liquid air, and suggest trying them in series with a battery and a lamp.

Expts. O and P and S are optional, and few ever do them.

Instructor asks all to try Expts. Q and R this week or a later week. We keep two or three sets of apparatus for Q and R on side-tables for several weeks. To obtain results for R that are easy to interpret, the electrodes should be of platinum and no rheostat should be included. Students should simply apply 2, 4, 6, 8, volts directly from a battery. Then the graph of P.D. vs. current will look something like Fig. 43-1 on p. 683; with the intercept on the axis indicating (only very roughly) the reverse EMF for the transfer between electrical and chemical energy in this electrclysis.

Students who have time, embark on Expt. M. The rest should be ready for M by next week.

We assign Problems 18, 19, 22, 27, 28, 29, 31.

Diode Tube.

In the fourth week, Expt. M (1) – P.D. vs. current for Radio Resistor – seems to be a necessary preliminary to the Diode Tube, M (2). It gives practice with a potential divider, and it establishes the idea of plotting the negative half of the graph as well as the positive half. Most students have time to do M (1), M (2) and M (3).

Instructor starts the lab with a short talk on potential divider, following the lines of p. 520 and asks students to try the experiment of Fig. 32-24, as a way of getting used to it. He asks them to go straight on to M (1), first reading the instructions on p. 521, and the note on "voltmeter-trickle difficulty." He explains that this experiment – and its graph which should be plotted at once – will provide necessary practice for the radio tube, and a useful comparison with it. Checking circuits for the potential-divider test and for M (1), (2), (3) gives the instructor opportunities for informal teaching. In checking M (3), he makes sure the filament has a suitable temperature to show saturation, but gives no other help or hint of what to expect.

At a stage when all have done M (3) and plotted its graph, Instructor gives a short talk about inferences from it – ideas of a stream of electrons – and he points out that we can convert a diode into an electron-gun by drilling a hole in the plate.

We assign Problems 27, 30, 32, 33.

A. C.; Model D. C. Power Line.

From this stage on, the program depends on equipment and on student speeds. Most students do the following the next three weeks; Ch. 32, Expts. T, U, V, W; Ch.41, Expts. C, E, Expt. H.

Expts. T, U, V; A. C. with lamp and D. C. ammeter; Diode rectifying A. C; Oscilloscope use to show current (by its p.d. across a sampling resistor) when alternating voltage is applied to resistor, then to diode. (We provide 5" oscilloscopes, already running, placed so that each pair of students finds one within reach.)

Expt. W: Model power line with D. C. The model consists of two 1/2 meter lengths of constantan, each of resistance 1/2 ohm, supported on 3/4' wood dowels that are clamped to the table. This experiment look trivial but proves useful.

These experiments and the experiments of Ch. 41 are the "pay-off" of the training with earlier circuit experiments; so we do not grudge the time that students need for these.

We go straight on to Chapter 41. There, EXPTS A and B (p. 655) are optional or demonstrations; but EXPT C and its explanations (pages 555-600) is an informal study of electromagnetic induction which we ask all to carry out.

Electromagnetic Induction. Ch. 41, EXPT C.

We provide no instructions beyond those printed in Ch. 41; and Instructor warns students they must depend on those and should read the intervening explanations. Each student gets a tray of apparatus: bar magnet, horseshoe magnet, keeper, iron rod, three coils of insulated wire, (40 turns, diameter 5 cms), iron core with axle (as in Fig. 41-6 iv). Also, a 1½ -volt cell, reversing switch, some connecting wires, and a Weston galvanometer.

Later in the afternoon, Instructor shows a demonstration generator with slip rings (and commutator) to give A.C. (and D.C.); and he provides help and apparatus for students who have time to try EXPTS D, G.

Model Power Line with A.C. Ch. 41, EXPT E.

This is done on the same day as EXPT. C. No measurements are asked for and it does not take much time; but it is a delight to see. (Some instructors suggest testing the high-voltage lines by touching quickly with fingers.) [We use filament transformers, 6-volt lamps and the "power lines" of EXPT W in Ch. 32.]

Triode Tube EXPT H (p. 662)

This is in a way the culmination of the series of experiments started in Ch. 32. To offer a formal "tube-characteristic" experiment at this stage would make little sense in this course. But if students can make a triode amplify and hear it at work, there is good reward. So we offer the instructions of pages 662-664 and ask all to do EXPT H, (1, 2, 3), with, say, a 6J5 tube. Instructors who are familiar with more formal schemes are advised to try out the measurements of H (2) beforehand.

For slower students who find the partial circuit-diagrams of Fig. 41-17 insufficient, we break our rule and draw a complete circuit-diagram – it is too late for discipline: we have failed, and we would rather have those students enjoy making their triode work. We draw that full diagram on a blackboard in a neighboring stockroom, where only the few who need it go and consult it.

Instructor gives considerable help over the use of grid bias and over the interpretation of amplification measurements.

MAGNETIC FIELDS AND LATER EXPERIMENTS.

Meanwhile, Electrostatics [Ch. 33] hâs been treated quickly in a few lectures, chiefly for the idea of electric fields; and magnetic fields are treated in part of a lecture. Knowledge of magnetic field patterns is needed for electromagnetic induction experiments (C in Ch. 41). Most students have seen iron-filing maps of magnetic fields at school, so we do not always spend a full lab period on them. If we are short of time, we run an exhibit of fields in the lab (Figs. 34-9 and 34-16 on pages 571, 576) while Ch. 32's EXPTS T, U, V, W, are finishing; and we ask students to sketch the fields made by currents.

Later experiments, on into modern physics, depend too strongly on available equipment for useful comment here, beyond a last appeal to keep the apparatus as simple as possible — so that the explanation of its construction and the instructions for working it do not bulk too large — and to give students plenty of time to learn to use the apparatus themselves.

TOURS OF RESEARCH ROOMS.

Where the teaching laboratories are near to research rooms — (as ours have the good fortune to be) — a visit to research rooms is of far greater value to students than we can even imagine. A half hour visit to one or two rooms, not a grand tour of many, seems best. There is a temptation to postpone such visits till late in the year "when students know about some of the things they will see" but I find that is a great mistake. An early visit, within the first month of the course, produces a sense of reality and asks students to look forward. If the owners of the apparatus visited will talk about their work, even quite technical explanations are accepted from them with pleasure and long-term profit.

We make a second set of visits, preferably to the same rooms, about three-quarters of the way through the year when students recognise pumps, counters, amplifiers, and ask more questions about the experiments. We usually offer still more visits at the end of the year.

All these visits are a proper part of a laboratory program and we believe they are very valuable, particularly if started early.

SECTION (IX). ANSWERS

"There is No Answer-Book"

Problems, in my own course, and in any serious use of my book, form a very important part of the teaching. If a physics course assigns plug-in formula problems, that ask the students to put numbers into a formula culled from text or memory, it produces a strange picture of physics. Those problems do very little essential teaching – they just give training in plugging into formulas – and they certainly do not encourage students to reason and think. At best, they provide a second-class check of students' reading. A few such problems do no harm and may help by giving a sense of quick success. Some simple numerical calculations are valuable for their result – and then I use them. In general, however, we should use problems to stimulate thinking, to demand reasoning, and to encourage students to teach themselves by working through several stages of an argument or a calculation. In such problems, which are essential teaching, the student's work in arriving at his answer is far more important than the answer itself. I am anxious to have all who use my book work out answers on their own, as a part of learning physics. So there is no answer book. If we provided an answer-book listing the final answers it would do the minor damage of encouraging short-circuit problem-answering in a hurry; and it might do the major damage of making people think that there is a single "right" answer to the discussion-problems which I believe are so important for promoting understanding. My colleagues who teach with me say that this applies to them as well – they find that their own workingthrough of the problems is a necessary part of their preparation for reading students' answers and for teaching in class. They say that reading students' answers brings them a lot of work but they agree it is a very important part of their teaching, well worth while.

Occasionally, the requirements of a problem are not as clear as the author intended. If a colleague meets such a problem and feels he needs my answer as well as his own, I hope he will send me a postcard: I will try to reply.

"Answer-Sheets" for Students

When assignments have been brought in, read and commented on, we sometimes save class discussion by issuing a printed "answer-sheet" with the returned assignments. These are a mixture of detailed answers and informal discussion. They do not always carry the argument through to the final answer – instead they may give some help and then reassign the problem.

For reasons discussed above, such answer-sheets are much best made out by the staff teaching in the course when they see what difficulties arise. Our own occasional sheets do not form a regular series: sample copies are not available for distribution; but a few specimens are printed below to show the kind of treatment we offer.

COMMENTS ON ASSIGNMENT DUE AT END OF WEEK 1

Chap. 1 Prob. 7 (page 15). In 2 secs travels 2^2 time as far, (4 times as far), as in 1 sec.; ∴ 4/4 inch, 9/4 inch and so on.

Chap. 1 Prob. 8 The rule is NOT $S = (1/2)at^2$ but quite a different one -- read the question carefully. Find the distance-travelled-in-one-sec by subtracting each total distance in prob. 7 from the next. The answers are: 1/4 inch; 3/4", 5/4", 7/4" ... Look at this series of numbers. There is a very simple scheme for them. (No need for a complicated story such as "adding something to half the acceleration". You need a simple statement in a few words.) If you did not get the numbers above it is because you did not read the question carefully.

Chap. 1 Prob. 9 RE-ASSIGNMENT (a) Re-read the hint. The distance-travelled-in-a-one-second-period is not "the acceleration"; it is something simpler. When you have thought out what these distances do represent, and when you remember that these distances are travelled in one-second periods WHICH ARE SPACED ONE SEC APART, you will know why you could have guessed this rule, and

(b) you will know why this rule applies to any motion with constant acceleration.

Chap. 1 Prob. 10 RE-ASSIGNED Now apply simple rule of problem 8 to the cyclists. This new rule will solve them all, except one, whose progress is an intelligence test. You should now be able to make a good guess that one, interpreting his motion in a new phrase of your own making. COURAGE

Chap. 1 Prob. 14 (a) balloon rises because NATURAL PLACE IS IN SKY: NATURAL BALLOON-MOTION UP.

(b) balloon rises because air buoyancy pushes it up, more than its weight pulls it down. (Buoyancy is not a mysterious force, it is just the result of air pressures all over the balloon. At the bottom of the balloon the pressure is slightly greater than at the top -- just as water pressure is greater at bottom of a pool than higher up -- and so the upward push on bottom exceeds downward push on top.)

Chap. 1 Prob. 15 (b) gold is very DENSE (not "gold is v. heavy" -- a pound of gold weighs as much as a pound of feathers). Therefore, air resistance has much smaller proportional effect on it than on less dense object like feather.

Chap. 1 Prob. 20 PUZZLE. Is there acceleration at the highest point? THIS IS AN IMPORTANT MATTER TO DISCUSS IN CLASS. (DO NOT CONFUSE VELOCITY WITH ACCELERATION, which is the rate at which velocity changes. At the top (vertex) the ball has no velocity. But is its velocity changing, even then? (Suppose I have $40.00 in the bank on Monday and I let money flow out of my account at a steady rate of 10 $-per-day. How much do I have on successive days? On Friday my balance is zero, but does that also make its rate-of-change zero? Plot a graph of bank-balance against time. Does the slanting line of the graph collapse where it passes through zero, with a horizontal jag there? Now try a graph velocity against time, for ball.)

Chap. 1 Prob. 21 RE-ASSIGNED. Problem 21 was intended to be a thought-experiment that would help the discussion of problem 20. In each case the observer sees the ball indulge in an ordinary-looking falling motion; but, from their different standpoints, B and C see different falling motions. Note that elevators B and C are not accelerating but only moving with constant velocity. There are no SUDDEN changes from slow to fast motion, but just ordinary accelerating motions; e.g., up slower and slower, stop, down faster and faster. If unsuccessful with this, please think it out again and write a new answer.

Chap. 1 Prob. 25 (a)(b)(c) A MISTAKE OF PLACING THE DECIMAL POINT IN ANY OF THESE IS A VERY BAD ONE. Try shifting the decimal point in your Income Tax form.

(d) thickness of paper: not far from 0.0001 meter, which is better written as 10^{-4} meter. Note that, for books, 1 leaf = 2 pages.

(d) This asks for explanation. Beware of omitting such explanations -- they are often more important than the preceding answer.

(f) Paper-thickness is somewhat more than 1,000,000 Å.U. (see * below)

(g) If atoms are 3 Å.U. thick, which are there MORE OF in the paper's thickness, single ÅU's or triplets which represent atoms?

* NOTE ON BEING SCIENTIFIC. It is scientific to be precise where precision is relevent to the matter in hand. It is not scientific -- in fact it is anti-scientific -- to be over-precise where that does not help the problem. For example, it may be a good estimate to say that you weigh 78.6 kilograms. But it is anti-scientific to extend this to impossible detail by saying, "I weigh 78.6291354 kilograms". Again, a sheet of paper of the text has, say, one third of a million atoms in its thickness. This is about 300,000. To call it 333,333 is anti-scientific foolishness; and 333,333.33333... is nonsense. Also, long words may be anti-scientific (see Problem 16 on p. 23).

COMMENTS ON SURFACE-TENSION ASSIGNMENT (CHAP. 6)

Ch. 6 Prob. 2 (Surface Tension Experiments) A scientist must be a combination of lawyer ("What are the FACTS, sir?"), a detective ("From that, my dear Watson, I INFER.....") and an artist ("Let's put some fire into this music, imagination into this poem. Let's make people feel its meaning more clearly.") Here, the lawyer is wanted first, then the detective. First say what did happen, then say what you can infer. Do not add vagueness by using long words where they are not really needed. Do not try to explain what happens by using other knowledge of doubtful pedigree, but just infer what you can from what you saw, combined with the discussion in lecture.In these you are asked to infer not explain. Explain would: be reverse logic

(g) (not shown in lecture) Bubble shrinks, blows away flame. Infer: air pressure inside soap bubble greater than outside. Also bubble behaves as if skin trying contract.

(h) When cross-bar is pulled down, film stretches; when cross-bar is then released, film pulls it up. Infer: film exerts a pull upward of cross-bar, presumably inward on any part of frame; film tries to contract, like stretched skin.

(i) When film inside loop is broken, the hole quickly becomes a circle. Since circle has max. area for given perimeter (thread length) the film, which fills remaining area of frame must have minimum area. Infer: film takes minimum area, like stretched skin.

(j) The spring shows a constant pull on it while the film is being stretched.
∴ tension is independent of area of film. But as the area changes, the thickness of film changes (when small sheet of film is drawn out into 10 times the area, it must thin down to 1/10 of the thickness).
∴ tension is independent of film thickness, over wide range

This is surprising and important. It tells us a thin film is just as strong as a thick one, over a wide range of thickness, (quite unlike the case of ropes or wires). ∴ the range of molecular attraction must be very small even compared with the film thickness, so that molecules in the surface layers find a full set of neighbors in the liquid within to attract them, even when film is stretched thinnest. The extra liquid in a thick film does not help to pull. Once again, this is a surface effect and this expt shows that only a thin layer near each surface produces this surface-tension pull. Of course if we could go on stretching the film, thinner and thinner, it must reach a stage where it is weaker, because finally when it approaches single molecule thickness it will come to pieces --- no pull at all. This has been done (N.K.Adam did something like this with his oil film on water) and the thickness at which a soap bubble becomes weaker is only a few molecule lengths. Moral:. the molecular attractions that produce "surface tension" have a very limited range (actually only a few molecule diameters).

(k) The Pressure in a small bubble must be greater than the pressure in a big one. This does not show the film of the small bubble is stronger --- expt. (j) just above showed that the film has same tension whether thick or thin. The film has same tension in both bubbles, but this tension makes a bigger pressure difference when it pulls around the sharper curve of a smaller bubble. When the locomotive tugs a long toy train round a sharp curve, the middle of the train sometimes falls over inward, for similar reasons. This does not happen on a gentle curve of large radius.

Ch. 6 Prob. 4 See actual demonstration of capillary depression with mercury.

Ch. 6 Probs. 5,6,7 RAYLEIGH'S MEASUREMENT, N.K. ADAM'S EXPTS. In this atomic age, you will fail if you cannot use standard form in arithmetic. (see instructions in Ch.1 App.A) because the atomic sizes are so small, and the numbers are so large, in astronomy, in atom counting, and in the federal budget.

Here are some of the answers. If you did not get these problems right (including the power of 10 correctly stated), please add them to the new assignment and retry for next week. Your working should include short explanations to show at each stage what you are calculating.

Ch. 6 Prob. 5 In carrying your calculation from 5a to 5b you need to use density of oil. If you are not sure how to use DENSITY, remember it is defined thus:

DENSITY = MASS/VOLUME and here you want VOLUME, so you say
∴ VOLUME = MASS/DENSITY (never learn this second relation; just start with the definition and use algebra)
∴ divide mass by density as above. For a further check, make sure the units that emerge are correct ones for volume. We divided (kilograms) by (kilograms/cubic meter) which is the same as multiplying (kilograms) by (cu.meters/kilogram) which produces cubic meters.)

Ch. 6 Prob. 6 (a) final answer 24.1×10^{-10} meter or 24 Angstrom Units. (d) answer, calculated from (c) on "1/10" basis, 4.6×10^{-28} kilogram per H atom

Ch. 6 Prob. 7 A rough graph will suffice -- worth trying. From that in turn you can infer a measurement that is much used in chemistry; and you can even make a rough estimate of the Avogadro number, or of the mass of an atom.

COMMENTS ON ASSIGNMENT DUE WEEKS 4 (and 5)

Ch. 7 Prob. 2 Wig-Wag (i) There are some hints in the problem itself. Just telling you the answer here would spoil the fun and do little good. Have another try at this or discuss in class. It would be hard to solve this by full algebra -- it needs calculus. (Therefore, avoid patronising help from superior neighbors. However, it is easy to guess the right answer by taking some courageous risks. Follow the encouragement of the question itself.)

(ii) You would have to time the wig-wag (a) empty, (b) with one kg on it, (c) with the unknown mass, X, on it. Pretend the platform alone has "equivalent" mass, m. (which you do not know and will never need to know). Then from the three timings you can eliminate m and find the ratio of x kg/1 kg.

Alternative method: Put X on the wig-wag and time it. Take X off and put some known loads, in kilograms, on it; and go on trying different loads until you find the one that gives the same timing as X. This is a "method of substitution".

Another alternative method: Time the wig-wag with a load of one kilogram, then with two kilograms, then with four kilograms, etc. Plot a graph preferably using the result of (i) to tell you what to plot for a straight-line graph. Then time the wig-wag with X on it; then locate the time on your graph and read off the value of X. This is a "method of interpolation".

Chap. 7 Prob. 3 After Prob. 2, try Prob. 3: a real problem in atomic physics.

Chap. 7 Prob. 6 Important for clearing up ideas of Mass and Weight. DISCUSS IN CLASS.

Chap. 7 Prob. 5 Let one pound fall freely. It falls with acc'n 32 ft/sec^2. Therefore the force pulling it is given by $F = M \cdot a - 1.32 = 32$ poundals. Therefore, Earth's field strength is 32 poundals/pound.

Chap. 7 Prob. 12 IMPORTANT: If you were wrong it was because of careless thinking or careless algebra. PLEASE RE-TRY. Distance and force are kept constant: So how will mass, M, be related to time t ?

Chap. 7 Prob. 13 30 newtons (b) 70 newtons (don't forget the friction 10)

Chap. 7 Prob. 14 A newton is defined as that force which will give a mass of one kg an acc'n of one meter/sec/sec.

(It will not do to say "moves a kg one meter in one second". This is not even true in the first second, starting from rest: it moves only half a meter!)

Chap. 7 Prob. 15 Just use $F = M \cdot a$ $5 = 20 \cdot a$ $\therefore$ $a = 0.25$ m/sec^2 Do not use a series of proportions --- looks too childish.

Chap. 7 Prob. 16 (a) $F = M \cdot a$ $F = 4.90 \cdot 4 = 19.6$ newtons

(b) The answer above is in newtons. Now you need to find the mass of iron that the Earth would pull with this force. Earth pulls 9.8 newtons on every kg of matter. $\therefore$ mass needed = ?...?? REASSIGNED

Chap. 7 Prob. 17 Discuss in class. Note that argument (b) is important.

Chap. 7 Prob 24. DO NOT INDULGE IN AN EGG-LAYING COMPETITION. Express all data in "standard form", such as 3.5×10^{-15} newtons. (See Chap. 11) If in doubt, ask in class how to multiply and divide powers of 10. Then all you have to do is to use COURAGE (not to be frightened of electrons or of very big and very small numbers) and ARITHMETIC (to handle the powers of 10) AND KEEP A CLEAR HEAD IN EACH CASE TO SEE WHETHER THERE IS CONSTANT SPEED OR CONSTANT ACC'N.

Prob 24 is RE-ASSIGNED. PLEASE TRY TO DO JUSTICE TO THOSE ATOMS. See note * below.

Make sure you can do Ch. 2 Prob 18 first. See the notes on it below.

Chap. 2 Prob. 18 (a) No. The unchanging horizontal motion (const.vel.,zero acc'n) continues quite unaffected by vertical acc'n -- we take the risk of extrapolating this knowledge from large-scale mechanics to unknown electrons.

(b) To calculate time taken to travel horizontal distance 0.30 m. at constant speed 6 million m./sec, you have an ordinary distance-and-rate problem like the ones in arithmetic, long ago. See footnote * below.

(Continued on next page)

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* NOTE If you are not sure whether to multiply speed by distance or, divide, or what, give yourself an easy example like this:

I DRIVE MY CAR FOR 2 HOURS AT 60 MILES/HOUR AND TRAVEL 120 MILES

If I want to calculate TIME TAKEN, 2 hours, I get this by dividing

$\frac{120 \text{ miles}}{60 \text{ mi/hour}}$. This reminds me that TIME = $\frac{\text{DISTANCE}}{\text{SPEED}}$

DO NOT BE
ASHAMED
TO USE
THIS TRICK

Chap. 2 Prob 18 (b, continued)

In this case, electron moves with constant horizontal velocity 6,000,000 m./sec and has to travel 0.30 meter horizontally.

$\therefore$ time taken = distance/speed = (0.30 meter)/(6×10^6 meters/sec) = 5×10^{-8} sec

PLEASE AVOID AN EGG-LAYING COMPETITION WITH CONFUSING HORDES OF ZEROS
Study Ch. 11, and make sure you can express things in standard form.

In standard form, (0.30)/(6,000,000) becomes $(3 \times 10^{-1})/(6 \times 10^6)$

so the answer becomes $(3/6) \times 10^{-1-6}$ or 0.5×10^{-7} or 5×10^{-8}

(c) NOTICE THAT THIS PROBLEM IS MUCH THE SAME IN FORM AS PROB. 17, JUST ABOVE, WITH CAR CRASHING OFF BRIDGE, WITH GRAVITATIONAL FIELD ACTING ON IT UNOPPOSED THEREAFTER. If you succeeded with that car smash and failed with this problem, all you need is COURAGE and the ability to do arithmetic with decimals.

For vertical fall, initial vertical velocity, v_o, is ZERO, and electron accelerates vertically down as if from rest. Use $s = v_o t + (1/2)\, at^2$

(d) For vertical motion, electron starts with velocity zero, and gains velocity with given acceleration. Calculate final v .

(e) Electron travels STRAIGHT (horizontally) before field, then in a parabola in the field; then after the field in a straight line again, but retaining the velocity with which it emerges from that field. And that final vel. has the original horizontal component 6 million m./sec and the gained vertical component (calculated in (d) above). So path is a straight line tangent to the parabola, sloping down with a slope that you should calculate from these two components.

(f) The answer: "too quick for gravity to have time to act" is silly. The reason, "because the electron is too small, or has too little mass, to be affected by gravity", is nonsense. The Myth•and•Symbol behavior includes electrons in a vacuum. The reason is easy to guess, but needs careful, accurate wording.

COMMENTS ON SOME OF ASSIGNMENT DUE WEEK 7

Chap. 8 Prob. 10 (a) Hammer loses all its momentum because nail exerts a force on it. (During the same time it exerts equal and opposite force on nail.)

$F \cdot \Delta t = \Delta(Mv)$. $\therefore F(0.002 \text{ sec}) = (2 \text{ pounds mass}) \cdot (10 \text{ ft/sec})$

$\therefore F = 2 \cdot 10/0.002 = 10{,}000$, and these are poundals, since $F \cdot \Delta t = \Delta(Mv)$ comes from $F = Ma$..

(b) HAMMER REBOUNDING FROM NAIL is done in the same way as 10(a) but you must remember that momentum is a vector and that the rebounding hammer moves backwards, so its velocity is -10 ft/sec, not +10 ft/sec, if its original vel was +10; and its momentum changes from + so much before impact to - so much after impact. This change is NOT zero. When your bank balance changes from \$20 in the black to \$20 in the red, the change is not zero -- try that on your bank. Now re-try prob. 10(b).

Chap. 8 Prob. 11 JET ENGINE. Use $F \cdot t = \Delta(mv)$. But what length of time should be used for t? Air is running through the engine at a rate of 35 pounds (mass) of air every sec. In any problem of steady flow like this (e.g., fire hose stream, or a stream of bullets) choose some length of time for t and calculate the mass of material "flowing" in that time, then when you use $F \cdot t = \Delta(mv)$ that chosen time will cancel out. Watch how we use 7 seconds as a specimen time in this example.

Suppose engine runs for 7 secs. Then in that time mass of air that goes through it is 7x35 or 245 pounds. And these 245 pounds of air change their vel from 300 ft/sec to 1500 ft/sec.
$\therefore$ change of momentum (in 7 seconds) = $245 \cdot 1500 - 245 \cdot 300$ pounds·ft/sec

$\therefore$ (force F)·(7 seconds) = $245 \cdot 1500 - 245 \cdot 300$ $\therefore$ $F \cdot 7 = 245 \cdot 1200$

$\therefore$ force F = $(245 \cdot 1200)/7 = 35 \cdot 1200$ = 42,000 poundals = about 1300 pounds-wt.

NOTE: The 7 divides into 245 to yield the original 35, so any other chosen period, such as 5 secs or 10 would give the same answer. Avoid using 1 sec -- it will muddle you.
(a,b) Thrust = 42000 poundals = about 1300 pounds-et.

(c) (i) Power = thrust·speed = (1300 pounds-wt)·(300 ft/sec) = 390,000 ft·pounds-wt/sec

NOTE: These are 'bad' units, because the pounds in them are 'bad' units of force, pounds-wt, and not good units of mass. (That is why we write them foot·pounds/sec instead of pounds·ft/sec which are good units of momentum where the pounds are proper pounds of mass.) However, these 'bad' units of power, foot·pounds/sec - meaning fact·pounds-wt./sec - are dear to the engineer's heart, and there is no hope of getting them out of common use.

(c) (ii) Power = 390,000/550 = about 710 horse-power.

COMMENTS ON SOME OF ASSIGNMENT DUE WEEK 8

How to do yourself justice in answering questions like the astronomy measurement ones

When he interviews you for a job, your host (unconsciously) multiplies together the grades he awards you for various important characteristics. He does not just add bits of credit for manners, appearance, intelligence, vigor, reports of industry, skill, knowledge, estimates of willingness, interest, intellectual awakeness, etc., to make a total of, say, 63% and call that good enough. He multiplies all the estimates that he considers important; so that if one of them has a grade of zero you are certain to fail. A similar story applies to the grading of answers to description + explanation problems. One piece of nonsense spoils the whole answer.

In answering a question that calls for a descriptive account, you have an opportunity to show your clear understanding, to do justice to your intellectual powers. Your answer should be clear enough, and adult enough, to enable your neighbor (who missed the class and did not do the reading) to understand the matter clearly -- and to admire your clear grasp. To make your reputation you need to keep the following essentials in mind. (If you try them you will find they do not add much extra labor.)

Diagrams should be given wherever they can make the explanation clearer. (A sketch the size of the palm of your hand is good. One the size of a postage stamp is confusing to the reader and makes him think you do not really understand. Examiners are apt to think very small diagrams conceal ignorance.) In many cases a diagram saves much worthy explanation -- "one picture is worth 1,000 words". Diagrams are used freely by good engineers, business presidents, and medical men who rise to being specialists, to make things quickly clear to other people.

Finish the Calculation. For example, where you have 7.5° in the meas't of radius of Earth, then say: ∴ circumference = (360°/7.5°) times distance, 500 miles.
∴ radius = circumference /2π = ... AND THEN WORK IT OUT.

In this very important case it is well worth finishing the arithmetic. Also that avoids your seeming to claim that you cannot finish quickly. Remarks such as, "The calculation is then continued by computation" or "The result is calculated by trigonometry" make a fool of you. Please avoid that mistake which does such poor justice to you.

Ch. 14 Prob. 1 SIZE OF EARTH. ESSENTIAL: (i) Diagram showing man, well, with vertical sunshine. (Add a note that the 2 stations must be in same longitude, to simplify geometry)

(ii) Statement of assumptions: Sun's rays parallel; observations simultaneous (Syene fact from library information for June 22)

(iii) Clear statement of measurements: Sunshine slant at Alexandria by measuring pillar and its shadow (NOON, June 22), and drawing simple scale diagram; distance 500 miles from Army pacers.

(iv) Clear simple calculations, starting with reasoning about angle at E's center, right through to final arithmetical result.

Ch. 14 Prob. 1 DISTANCES OF MOON, SUN. As above, give clear diagrams and carry the calculation through to an arithmetical result, without using trig tables, without using vague remarks like, "Then...set up a proportion" or "He computed it by trig" -- which would ruin you in an interview.

Ch. 13 Prob. 5 (c)(i) Latitude is (90° - A) where A is angle between local vertical (= Earth's radius) and the Earth's NS axis. ∴ measure angle between plumb-line and pole-star directions. (Why is it safe to do that at any time of night, not just midnight?)

(c)(ii) Measure angle between noonday Sun (highest in sky) and plumb-line (Earth radius). This would be latitude if Sun were exactly overhead at the equator; and that does happen at each equinox. You must either wait until it is equinox or know what month you are in and use the fact that noonday Sun is 23.5° north of equinox height in June, 23.5° south of it in December.

(c)(iii) REASSIGNED. Longitude, how far around the Earth you are, cannot be got by observing the star pattern (or Sun) alone, because that pattern itself turns around and around night after night. WHAT IS THE ESSENTIAL AUXILIARY INSTRUMENT? This is an intelligence test.

(d) When would that auxiliary instrument become available to navigators? Before that moon-eclipses offered the only reliable substitute.

When there is a total eclipse of the Sun it casts the Moon-shadow on a fairly small patch of Earth. As the Earth spins and the Sun and the Moon move, this patch sweeps across the ground marking a swath from which the full glory of the eclipse can be seen. People outside the swath see only a partial eclipse, -- different views for observers in different places. However, when there is an eclipse of the Moon the shadow of the Earth falls on the Moon, on certain actual moon mountains, etc. In that case, does the eclipse of the Moon look the same to observers in different places, or different?

COMMENTS ON SOME OF ASSIGNMENTS DUE WEEKS 10, 11

Ch. 17 Prob. 1 Thickness 0.024 inches or 1/40 inch. How many pencil-leads side-by-side to one inch? How many sewing threads, side by side?

Ch. 17 Prob. 3a Near star would make a small apparent motion along remote stars, repeating in course of ONE YEAR. (i) For near star near ecliptic, path would be to-and-fro in a flat ellipse. (ii) For near star near pole of ecliptic: small circle. (See also ABERRATION of starlight, in Ch. 31. Aberration gives rather similar, but much larger shifts -- the same for stars at all distances)

3b (i) For Tycho's smallest angle, 200,000,000 = (circumference 2πR)/(360 x 360)
∴ R = about 4×10^{12} miles

3b (ii) For actual star parallax,
4 yrs = 4 x 365 x 24 x 60 min. = about 2×10^{6} min.

For nearest star

Arc = 2×10^{8} miles and light takes 16 minutes for this

Radius = 4 light years = 2×10^{6} light-minutes
= 2×10^{6} light-min x (2×10^{8} miles/16 light-min)
= $10^{14}/4$ miles or 25×10^{12} miles (about 6 times as far away as in (i))

∴ angle at star = $360^\circ \times (\text{arc}/2\pi R) = 360^\circ \times 2 \times 10^{8}/2\pi\ 25 \times 10^{12}$
= 1/2000 of a degree or 1/6 of angle in (i)

∴ Tycho would have failed by a factor of about 6.

Thus, actual star parallax, now known, shows that Tycho would have failed to detect parallax of nearest star. To make the comparison, USE COURAGE + COMMON SENSE and stick to one set of units -- not miles and minutes mixed. Then you will be able to say: "The nearest star is... times as far away as it would have had to be for Tycho to detect its parallax mation." (It is silly to say "Tycho's error was....." He made no error. He could not, and knew he could not, measure small enough angles.)

Chap. 21 Prob. 3 (page 302) For motion in a circle, acceleration is INWARDS to center, v^2/R, and this needs a real inward force which must be provided by real agents. If the real force is not provided, the moving mas, m, will fail to pursue the orbit but will continue (not "fly off") along tangent.

(a) At A, acceleration is horizontally inwards to the center. The force must be horizontally inwards, to the right.

(b) PUSH OF THE TRACK provides the needed inward force.
(This is a real push. Momentum is not a force. There is also an outward push, but that is the push that the truck exerts on the track -- that is a force ON THE TRACK, not a force on the truck.)

(c) EARTH ALSO PULLS TRUCK DOWNWARD (This force is called the truck's WEIGHT.)

(d) This force, weight, accelerates truck's motion along track at A.
(There are also friction forces that act on the truck: air friction, and rail friction. These retard the truck when it is moving downwards. When the truck is moving upwards on the other side of the loop, weight decelerates it, and friction forces still decelerate it.) (Except for these small friction forces --- and some still smaller forces of buoyancy, Sun's attraction, etc. --- there are no other real forces on the truck. The upward momentum that it has at A does not constitute force. Momentum is not a force -- it is something that needs a force to change it.)

(e) At B, acceleration is down towards center. Force must be downward.

(f) Force provided by PULL OF EARTH (truck's WEIGHT) and PUSH OF TRACK if any.

(g) Cheap explanation, that smells of formula worship: if truck moves slower much smaller force is needed because force is mv^2/R and when v is made smaller v^2 becomes much smaller. (Halving v reduces v^2 to 1/4 as much as before.)

Better explanation: the needed force is change-of-momentum/time. For a given small piece of track, the time spent by the car is doubled when the speed is halved. On that score the car needs only half as big a force. But at half speed, the change-of-momentum (for a given small piece of track) is halved. So the needed force is halved again. ∴ needed inward force is 1/4 as big.

(h) Earth pull, weight, is always there and may provide too much force downward even without any help from the track. In that case the truck moves in a sharper circle than the loop of the track -- it falls too fast -- and leaves the track.

Ch. 11 Prob. 11 Error is .3% in whatever units you work. If you are 0.3% taller than your brother that is true whether both heights are in feet or both in inches (or meters or cm.). Ch. 11 Prob. 12 0.005%. MAKE SURE.

PART OF ANSWER-SHEET FOR ASSIGNMENT DUE WEEK 19.(See Wk 20 sheet for re-assigned problems)

Chap. 30 Prob. 8. HELIUM SPECIFIC HEAT If you did not get result 0.73, you should try this again or ask in class. This is an important prediction, as a test of our theory. Specific heat should be 0.73. IT IS, when measured carefully, ABOUT 0.74.

Chap. 30 Prob. 11 (a) evidence: surface tension
(b) evidence for little attraction: BOYLE'S LAW (otherwise when volume is small and molecules are close together, attraction would pull molecules together and measured pressure would be LESS than that predicted by Boyle's Law. Or, the evidence is the SMALLNESS of Van der Waals constant "a" in $(P + a/V^2)$. If molecules are so bulky that they take up an appreciable fraction of the volume of the container, we predict another modification of Boyle's Law: measured P will be larger than expected, at very small volumes. It is unlikely that air suffers both effects appreciably at ordinary pressures and that these exactly compensate. And the closeness of real gases to Boyle's Law at low pressures gives full assurance)

Vague statements about gases filling container are insufficient; the molecules might still attract appreciably.

(c) SKETCH asked for. Attractions have resultant pull INWARD to liquid.

(d) Average KE is not enough. Such molecules, if they escape, fall back. Since the only successful escapers start with more-than-average KE, the average of the KE's of the molecules left in the liquid must be less than before. UNLESS SUPPLIED WITH HEAT FROM OUTSIDE, liquid's molecules' average KE will grow less and less as time goes on.

(e) COOLING means lowering of av. KE of molecules. Since av. KE is lowered, liquid cools.

(f) The escaping molecules are merely those that were temporarily richer, just after some lucky collision hitting them outward extra fast.

Chap. 30 Prob. 20 How does the ball store its energy -- i.e. in what from? -- when it is in the most-squashed-stage, momentarily stopped at the wall? Think about this. There will be discussion later.

PART OF ANSWER-SHEET FOR ASSIGNMENT DUE WEEK 21.

Chap. 32. Prob. 16 (a)(b) Cottage uses 5 amps. THIS MEANS THAT 5 COULOMBS FLOW THROUGH COTTAGE IN EVERY SECOND.

Cottage uses 5 amps at a p.d. of 100 volts. THIS MEANS THAT EACH COULOMB PASSING THROUGH COTTAGE TRANSFERS 100 joules, FROM ELECTRICAL ENERGY TO HEAT, ETC. IN COTTAGE
∴ 5 coulombs flow through cottage per sec, each delivering 100 joules.
∴ power = (charge/sec) (energy-transfer/unit charge)
= (5 coulombs/sec)(100 joules/coulomb) = 500 joules/sec = 500 watts
Similarly, power supplied by power-plant to hold system = (5)(140) = 700 watts

(c) ∴ 200 watts of power wasted by heat developed in wires: heats the air.

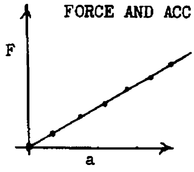
(d) p.d. wasted is 140 volts - 100 volts.
THIS MEANS: EVERY COULOMB IS GIVEN 140 JOULES BUT DELIVERS 100 JOULES AT FAR END.
THERE, EACH COULOMB DELIVERS 40 JOULES (to heat) IN PASSING THROUGH THE SUPPLY WIRES.
We assume the two wires are symmetrical and share the heating loss equally.
∴ p.d. between the ends of each wire is 20 joules/coulomb or 20 volts.

PART OF ANSWER-SHEET FOR ASSIGNMENT DUE WEEK 7

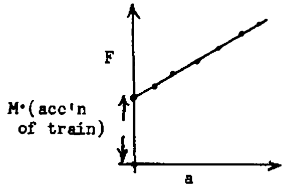
Chap. 8 Prob. 19 SQUIRREL. (i) 0.1 kg; 0.6 kg (ii) 0.1 x 6 kg·m./sec
(iii) 0.1 x 6 0.6 V ∴ V = 1 meter/sec.

(b) The answer is NOT less than 1 m./sec. If you got this wrong, please try it again, since it is needed for kinetic theory of gases. Remember: MOMENTUM IS A VECTOR; MASSES MUST BE ACTUAL MOVING MASSES to be multiplied by velocity to give momentum, -- so squirrel's mass us 0.5 after the collision. State each lot of momentum RELATIVE TO STATIONARY OBSERVER, and calculate one grand momentum equality, from "before" to "after", with no caculation by separate stages. Remember +, -, signs.

Chap. 7 Prob. 28+29 Discuss in class. When the expts are done in accelerating train -- along the line of acceleration -- experimenter must either make the block of ice or truck accelerate to keep up with the train, or let it get left behind with increasing velocity. Thus he finds he must use an extra forward force M· (acc'n of train) with no apparent gain, except just to keep his experimental apparatus in front of him.



GRAPH OF EXPERIMENTS ON FORCE AND ACC'N IN A TRAIN AT REST OR MOVING WITH CONSTANT VELOCITY.



GRAPH OF EXPTS IN A TRAIN MOVING WITH CONSTANT ACCELERATION IN THE DIRECTION OF THE MOTION IN THE EXPERIMENTS.

COMMENTS ON ASSIGNMENT DUE WEEK 20

Chap. 30 Prob. 20 THE RUBBER BALL (Even if the ball has no air inside but a thick rubber wall, the ball will bend and compress and stretch its rubber wall when it is squashed against the wall, storing up strain potential energy which is then released and reconverted into kinetic energy as the ball bounces back. When there is air in the ball the air also takes part in this process, storing energy as HEAT, not as strain energy, during the squelch. The following explanation shows what happens to the air when the rubber is thin, flexible, and unstretchable.)

As the moving ball comes to rest (squelch) against the wall, the air molecules meet an approaching piston (this is the wall of the ball where it is being pushed and flattened by the wall) and, therefore, rebound from that piston faster than before. These faster molecules are hotter. THAT IS HEAT, for a gas, THE KINETIC ENERGY OF MOLECULES WHIZZING ABOUT. The ball is now at rest, badly squashed against the wall. As its molecules are moving faster than before, the air pressure is increased above original atmospheric.** So the ball pushes the wall with extra pressure and the wall pushes the ball with extra pressure, and there is a resultant force pushing the ball away. The ball accelerates, moves away from the wall. The air molecules are hitting a receding piston during this process, so they lose speed, lose random K.E., lose heat and cool back practically to original temperature.

(**NOTE: If ball is compressed to smaller volume, there is also a Boyle's-Law increase of pressure, but so far as this is due to smaller volume making impacts and other collisions more frequent, it involves no increase in stored energy. There MUST also be a temperature-rise, and that shows the storage of energy (temporarily) as heat -- mulecules moving faster.)

A ball of solid rubber rebounds elastically. During the squashing process, it stores returnable strain-energy (rather than heat). The rubber molecules are hitched together strongly, and you may picture the deformation stretching their hitch-springs. Then the molecules snap back and return the energy from strain-storage; because the rubber exerts the same forces "on the way in" (squashing) as "on the way out" (expanding again) -- this is the essential characteristic of an elastic collision. (Some experts would say that a hunk of rubber is almost one grand molecule, because its components are so well hitched together.)

A lump of lead behaves differently because the binding forces hitching its atoms together are not so strong, so when the lump is pushed by hitting the wall, it stays pushed around because the atoms have taken up new groups. Every atom is tied to neighbors by springy forces, and when it is pushed around to new neighbors it leaves its previous neighbors in violent vibration. Thus, during the deformation, the heat energy of the lead (energy of atomic vibrations) is increased. And afterwards it stays increased, -- because there is no way in which this jangling mess of vibrations can gang up into a one-direction force to push the wall away again and make the lump rebound. So all the lump's original K.E. is turned into heat. (NOTE: In solid lead, we should speak of atoms rather than molecules. The atoms are arranged in a regular crystalline lattice.)

Chap. 30 Prob. 8 SPECIFIC HEAT OF HELIUM
Pressure x volume = $(1/3)\ Nm\ (\overline{v^2}) = (2/3)$ K.E.

∴ K.E. = (3/2) p x V = (3/2) x (100,000 newtons/sq. meter)(22.4 cu. meters) for 4 kgs of helium at atmospheric pressure

But the K.E. also = heat needed to warm the molecules* from absolute zero to 273°K
= 4 kg x (sp.heat) x 273° = (1092) x (s) Cals. = 1092 x 4200 x (s) joules
∴ 1092 x 4200 x (s) = (3/2) x (100,000) x (22.4) ∴ s should be 0.73

---

* Of course it is risky and unreasonable to imagine the helium warmed up, as a perfectly behaved gas, all the way from absolute zero to 0°C. Fortunately it is not necessary to do that. The $273C^\circ$ temperature rise really cancels out because the same 273° is contained in PV for 0°C. All we need to do is to take a ONE$^\circ$ temperature rise, say from 0°C to 1°C. Calculate the increase in PV for that.

Chap. 32 Prob. 9 A piece of zinc and a piece of copper placed in acid form a simple electric cell (a one-cell battery). No current is produced until an outside wire connects the copper to zinc. Then "positive current" flows from copper to zinc outside through the wire and from zinc to copper (by ions in solution) inside. When that current flows, zinc dissolves and hydrogen appears, on the copper. When the metals are thrown loosely into acid hydrogen appears and heat is released because we have small short-circuited electric cells. The zinc touching the copper in the acid is equivalent to a wire joining separated zinc and copper. We get short-circuited current, heat, hydrogen. In fact, the hydrogen appears even here at the copper. That is why in chemistry manufacture of hydrogen with zinc and acid is improved by adding copper -- otherwise, it is better to use impure zinc.

Chap. 30 Prob. 9 The prison cell for one molecule at 1 Atm. pressure, D^3, is 10 molecule diameters wide, D = about 10 d. Its volume, D^3, = 10d·10d·10d
At 125 atm, the volume is squashed down by factor 1/125 (BOYLE)
∴ new volume, new D^3, = $\frac{10d \cdot 10d \cdot 10d}{5 \cdot 5 \cdot 5}$ = 2d·2d·2d, ∴, ...

COMMENT ON ASSIGNMENTS DUE WEEKS 25 - 27

SEVERAL PROBLEMS IN Ch 38 and Ch 39 NEED JUST THE FOLLOWING THINGS:

When a gas carries a current, the gas has in it some ions, which are the carriers

Ions are electrically charged atoms or molecules, or electrons

Ions can make ions by collisions: one ion knocks an electron off a neutral atom or molecule making a new pair of ions, + and - .

Ions make more ions by collision because they are charged and have an electric field that extends some way out, to pull or push an electron off a neutral particle. (A neutral atom can knock an electron off another neutral atom if thrown fast enough, since it too has an electric field inside; but it must come to close quarters, so the effective target-area is small; and it cannot be given the necessary energy by an electric field. If done by heating, that needs 100,000°C)

A moving ion (or neutral atom) cannot make new ions by collision unless it has such high speed that it has enough K.E. to lose in detaching an electron from the victim.

In a strong enough electric field, an ion gains enough K.E. between one collision and the next to make new ions at each collision. That requires the electric field to exceed a certain minimum strength (for a given MFP). Then there is a spark. With less than the minimum energy, any ion (or atom) makes an elastic collision.

For any particle with charge e, accelerated by gun with P.D. V, kinetic en. $1/2\ mv^2 = Ve$

For any particle with charge e, moving across magnetic field H, catapult force is $10^{-7}evH$

A circular orbit needs a force mv^2/R

Chap. 38 Prob. 2 The hydrogen would be present if far too small quantities to be detectable by any chemical method. (In fact, mass-spectrograph, here under discussion IS the sensitive way of looking for it). One good way of pinning the crime on the criminal is to offer greater opportunities for more of the same crime) Use that here: make an obvious move in using the apparatus. (If still not sure: ASK)

Chap. 38 Prob. 3 (a) The ion that might make 36 or 38 is NOT H^+, (which makesmark at 1), but the compound ion HCl^+. (b) To test for that "with the same apparatus", give greater opportunities for the same crime. (See Prob 2's answer above)

Chap. 38 Prob. 4 Use elementary algebra+courage. Remember: Q is the charge e; and the velocity v in $1/2\ mv^2$ is also the velocity in Qv. Do the algebra and you will find that the velocity of every ion that gets through the selector is $10^7 V/dH$. It does not depend on the ion's mass or charge. Then after that, in the plain magnetic field, you will find ions of double mass focus in circle of double radius.

Chap. 39 Prob. 2 (a) Some molecules have been ionized. (b) At the flat value, (A), ions are being swept across just as fast as they are being manufactured (without having time to recombine). (c) When there is a spark, ions are making more ions by collision, because they gain enough energy travelling one MFP in strong electric field.

Chap. 39 Prob. 9 (a) It would be very unwise just to assume that the substance is a single radioactive one with, therefore, a single, constant, half-life. Many a radioactive product of bombardment is a mixture. Here, the question suggest as single substance, but you can check that. First subtract the background, 20; then look for halvings. There is one case of halving in 6 hrs and another of falling to 1/4 in 12 hrs. Therefore, over the whole 20 hours, it shows a half-life of 6 hours.

(b) Take logs; (logs to base 10 are just as good for this purpose as the much-more-difficult-to-find logs to base "e"). Then in 2 hrs the log of activity falls from 3.0000 to 2.0000. Therefore, log(activity) falls by log of 2, which is 0.301, in a total time (2 hours)(0.301/1.0000) or 0.602 hours or 36+ minutes.

Chap. 39 Prob. 12 (a) From straight tracks infer that though there are many collisions with light electrons, there are practically no collisions with things of mass comparable with alpha-particle's. ∴ ATOMS ARE MOSTLY HOLLOW. (b) Fork shows a collision with something of comparable or greater mass. One arm of fork is continuing alpha; the other is recoiling nucleus that was hit. Since such hits are very rare, nucleus must be very small -- or its electric field must be very weak except very close to it, which is true of an inverse-square-law repulsion.

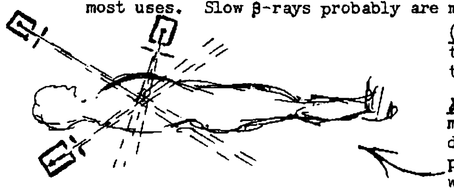
Chap. 39 Prob. 13 (a) If the collision is elastic, and if the moving alpha-particle hit something that was practically at rest, THE ALPHA-PARTICLE HIT SOMETHING OF THE SAME MASS AS ITS OWN. (Note that we have stated the assumptions in the "if" remarks).

(b) Since the two tracks look the same, and since we have guessed the masses are the same, WE INFER THAT THE CHARGES ON ALPHA-PARTICLE AND HELIUM NUCLEUS ARE THE SAME. (A neutral helium atom has two electrons; but in the smash of this nuclear collision those electrons are detached and left behind -- try to hold on to your books when you are hit by a Boy Scout moving at 10,000 miles/sec. Incidentally a Boy Scout hurled fast enough (over 185,000 miles/sec) at another Boy Scout would go right through him -- this is just alpha-particle-scattering done on a vast cooperative scale -- but both boys would be left very badly ionized).

Chap. 39 Prob. 16 They have no electric charge; ∴ have no electric field; and are not affected by electric fields; exert no forces on electrons or positive nuclei by electrical means; ∴ make no ions, ∴ no water drops gather on their tracks. (Very near a nucleus, neutrons show "nuclear forces" that do lead to collision effects.)

Chap. 39 Prob. 17 (a) Those that are stopped. Those that pass through have NO effect and do NO damage (e.g., gamma rays for most of their trip). Even those that make ions as they go, as α-rays do, do most damage when moving slowly. This is a momentum-problem -- at low speeds the projectile has more time near some atom's electron to give it enough momentum to get it away. (Note: there are also small effects of γ-ray collisions with electrons: see "Compton effect" in Ch. 44).

(b) (i) α-rays have great effect on outermost skin, but are not penetrating enough for most uses. Slow β-rays probably are more useful.



(ii) β-rays. (iii) β-rays, if you can get the source of them near the region to be treated.

γ-rays only if you can send them in from many directions in turn, so that they do not do too much damage to intervening flesh, and produce large effects in the common region where several beams of γ-rays cross.

Chap. 39 Prob. 18 (a) Danger depends on how long you carry it around, and how close to your body. If the samples have atoms of much the same mass, they contain about the same number of atoms in 1 gram. Half these atoms disintegrate in one half-life, and eject (α)/β/γ rays which may make ions in your flesh. If the short half-life is 5 minutes and the long half-life is 30 minutes, then carrying the samples around for ten minutes will give far greater risk from the short half-life one — 3/4 of its atoms will have ejected rays, while far less of the other will have ejected rays. But if you carry both around for a week, practically all of each will have disintegrated -- you will have suffered the same bombardment from both, chiefly in the first hour or two. Though the short half-life atoms deliver their rays a little earlier, you do not recover much as time gives on so the damage would be much the same.

However, in general, if the exposure period is short compared with half-life of either sample, the sample with shorter half-life does more damage.

If you compare samples that have equal activities (measured in disintegrations/sec or measured in millicuries), then in fact you have less atoms of the short half-life atom, and may fear less damage from it. The activities would then start equal, but the short half-life sample's activity would die down faster; so in a long exposure you would have less radiation from it. Since activities are the important measures in many estimates of radioactive materials -- in buying and selling, in setting up safety rules, etc. -- samples are usually specified by activity in "millicuries". A curie is a sample which has the same number of disintegrations/sec as 1 gram of radium. (b) Far less safe for experimenters.

NOTE ON RADIATION DANGER:

Radiations such as X-rays, rays β rays, are dangerous because they make ions when they are absorbed in human flesh. This abnormal ionization may lead to inflammation, including surface burns that heal very slowly, or to grave changes such as cloudiness in eye material, and possibly to genetic changes. Neutrons present similar dangers by indirect action -- they occasionally hit protons (plentiful in the water of human body) and give them enough energy to make ions. The ionizing power, which represents the danger, in a stream of radiation, is commonly measured in milliroentgens per hour. One milliroentgen is a unit of (radiation-stream intensity)·(time) or total dose per unit mass. One milliroentgen is defined as the radiation dose that makes about 2 billion pairs of ions in every gram of material placed in the stream.

The extent of time over which the dose is received makes some difference. Given time, the body makes some recovery; but in general much of the damage seems to be cumulative. Dangerous radioactive sources and machines such as X-ray tubes, are rated in milliroentgens per hour for a receiver at some standard distance.

Dangerous dosage:

50,000 milliroentgens of dosage to the finger or arm or other comparably small fraction of the body: No great reaction.

50,000 milliroentgens of dosage over the entire body: Nausea, substantial changes in blood count. Appreciable fraction of fatal reactions in the very old or feeble.

600,000 milliroentgens of overall body dosage: more than half of those so exposed will not live.

SECTION X SPECIMEN PROGRAM OF TOPICS AND ASSIGNMENTS FOR ACTUAL COURSE

NOTE..Where a problem is assigned some time earlier than the treatment of its topic in lecture or class, that is intentional and important preparation. Where a problem is assigned some time after its topic is treated, it is meant to promote further study. But where a problem is assigned practically parallel with its topic's treatment, students may need the teaching of lecture or class for the problem; and in some cases the scheduling of classes and problem-work may be critical. Then a problem may have to be assigned a whole week later -- or in other cases a week earlier -- than the place listed here. However, such problems are intended to promote current learning, so we do not shift them farther than necessary. Most problems are not so critical in this respect as they look: if assigned a little too early, they simply demand more careful reading and give good teaching in advance.

KEY:
(P) = "Preliminary problem", printed at the beginning of a chapter.
(T) = "Typewritten problem", a dissected problem.
(L) = "Laboratory-topic problem". The placing and use of this should fit with lab program.
[ ] = suggested as an optional problem

WEEKS: In this specimen, the year's program is divided into two semesters of 15 weeks each. Where a week is shown broken into two parts, these refer to first and second lectures in the week. (The actual program runs with 2 lectures and 1 or 2 classes per week.)

WEEK	MATERIAL FOR LECTURES AND CLASSES		ASSIGNMENT (Issued before week begins required by end of week)				LABORATORY
	CHAPTERS (pages)	TOPICS	READING Ch.	PROBLEMS Ch.	Problem Numbers	(pages)	
		ASSIGN →			PRELIMINARY PROBLEMS. As soon as course starts, assign the following to be answered in first few days. Preliminary prob. for Ch. 1 (page 2) 1(P),2(P),3(P),4(P),5(P),6(P)		
Week 1	1 (pp. 3-16) (p.22)	Introduction: block+gap course falling objects: why? how? acceleration down slope monkey and gun ------ acc'n up-and-down slope stroboscope and water drops M.K.S. units guinea and feather	1 1A 2 (1B) (3)	1	7+8+9+10 11,12 14,15,20,21,25,26 [22,27,30]	(p.15) (p.17) (pp.24,25) (pp.24,25)	"Open lab" * Falling bodies, and projectiles. (Ch.4 EXPT A. p.65)
		ASSIGN →			→DUE		
Week 2	1 (pp.16-23) 1A 1B 2	acc'n down slope: s vs. t derivation of $s = v_0t + at^2/2$ tests of $s \alpha t^2$ motion of projectiles motion with no force motion with fluid friction ------ measurement of "g" electrons in electric field vectors	1 1A 1B 2 3	1 1A 1B 2 3	19 A-1, [A-2], B-1,2 B-3(T),4(T),5(T),6(T) B-8+9+10+11, 15 1, [2+3], 4, [5] 7,8,9,10,11,12,13,[14] 1	(p.24) (pp.29,30) (p.31) (pp.32-34) (p.35) (pp.40,41) (pp.45-47) (p.55)	Acceleration of Wheel Rolling down incline (Ch.4 EXPT C page 65)
					→DUE		

WEEK	MATERIAL FOR LECTURES AND CLASSES		ASSIGNMENT (Issued before week begins required by end of week)				LABORATORY
	CHAPTERS (pages)	TOPICS	READING Ch.	PROBLEMS Ch.	Problem Numbers	(pages)	
		ASSIGN					
Week 3	3 7 (105-108)	forces add as vectors demonstration and discussion of equilibrium problems ⋇ cart on hill ⋇ Car on level track: const. v	3 7 (pp.105 -110)	7 2 1B 3 1	1 2+3 (if not done before) 12,16 17,18, [19] B-7, [B-20, B-21] 3, 4?, 5, 6? 24	(p.108) (p.40) (pp.46,48) (p.51) (pp.34,35) (p.59) (p.24)	Discussion of Rolling Wheel expt: techniques; graphs; tangents drawn. Analysis quest.(p.65) assigned, due next week. Visits to Research rooms.
		ASSIGN			DUE		
Week 4	7 (109-118) (120-128)	car on level track: F and a F and m wigwag: discuss mass ------ discussion of F - Ma "g" as field strength "demons": demonstration and brief discussion	7	7	7(T),8(T) 5 12,13,14,15,16,17 19,24	(p.127) (p.126) (p.132) (pp.132,133)	Investigation of Springs (Ch.4 EXPT B p.65)
		ASSIGN			DUE		
Week 5	7 8 (135-139)	demonstrations of F = ma (time of contact and force, for kicking football; models of problems 8,10 of Ch. 7) ⋇ ------ F = ma changed to F·Δt=Δ(mv) expts. on momentum conservation	7 8	7	2+3,6 9(T),10(T) 18,23,26,27,31	(pp.122,126) (p.128) (pp.132-134)	Springs (continued)
					DUE		

⋇ MEANS "MATERIAL EASILY OMITTED IN SHORTENING THE COURSE"

DEMONSTRATION EXPTS. Week 1. Expts of Figs:1-3; 1-7; 2-40; 2-7. Guinea + feather. Meter cube; kg; liter of water,(for MKS units)

Week 2. Expts of Figs: 7-10b(with slanting track); 2-5(with rectangular grid). Dry ice coasting; steel balls falling in viscous oil. Expts of Figs: 2-18; 2-27; 1-23; 1-14. Oscilloscope with A.C., microphone etc.

Week 3. Expts of Figs: 3-1, 5a, 6, 8+9+10; 3-12; 7-8; (7-10a). Dry ice coasting.

Week 4. Expts of Figs: 7-11a, b and 7-11c (doing Figs 7-12+12+14); 7-26. // Expts of Figs: 7-31 (with rough balance marked in newtons); 7-32. Rough calibration of spring bal. in newtons (top of Fig 7-33). Expt of footnote 4 on page 344.

Week 5. Demonstrations of F=ma calculations: football (time-of-contact and final speed measured, to calculate force); models of problems 8 and 10 of Ch. 7. // Expts of Figs: 8-1; 8-5; 8-4 (models with colliding pendulums, photographed with polaroid camera and multiple flashes.

WEEK	MATERIAL FOR LECTURES AND CLASSES		ASSIGNMENT (Issued before week begins required by end of week)				LABORATORY
	CHAPTERS (pages)	TOPICS	READING	PROBLEMS			
			Ch.	Ch.	Problem Numbers	(pages)	
Week 6	8 5	conservation of momentum demonstrations; discussion ------ collision; elastic, inelastic elasticity demonstrations * discussion of law	8 5 (12,13)	8	1(T) 5(T),6(T),7(T),8(T) 3,4	(p.138) (p.150) (pp.142,143)	Discussion of Springs expt: council on results Start Pendulums: EXPT D(0) Ch.4 page 66 (Supersprings* continue)
SURFACE TENSION LECTURE and/or FLUID FLOW AND BERNOULLI LECTURE sometimes given here, with ensuing problems. See Week 15.							
Week 7	12	ASTRONOMY primitive man and astronomy facts: motions of stars, Sun,Moon planets; eclipses, zodiac ------ Babylonians et.al. early Greeks: idea of a theory; Thales, Pythagoras, Eudoxus	12	7	28+29	(p.133)	Pendulum investigation EXPT D (1). ? D(2) Ch. 4 page 66 (Supersprings continue)
	13		13	8	9,10,11,16 17,19,27	(p.151) (pp.152,153)	
	14 (223-231)		14				
Week 8	14 (231-240)	Greek meas'ts: size of Earth; distance of Moon, Sun Aristarchus, Hipparchus epicycles and eccentrics precession ------ Ptolemy medieval astronomy	14	13	1,2,3,5	(p.222)	Pendulum: EXPT D (2)(3) (Assign: plot 2 graphs, compute g,by next lab) Run through (i)-(v) of pendulum argument;issue sheets of it to be done by next lab. (page 171)
			15	14	1	(p.240)	
	15			7	24,25	(p.133)	
				10	1(T) (after pendulum lab, before S.H.M.)	(p.171)	

* "SUPERSPRING EXPTS." * When the Springs expt. finishes in lab, students who have a good unfinished investigation that they wish to continue may be given permission to continue for several, or even many, more weeks. Their experiment is declared a "superspring expt" and they are assured of a special grade instead of grades for pendulum expts. However much they miss of other experiments, such students seem to make greater long-term gains from their superspring expt.

ASTRONOMY. Many of the sketches of the astronomy chapters are shown as slides and then exhibited in corridors as large posters, mounted on cardboard. A few portraits are shown. A very large eclipse-diagram, drawn to scale, shows Figs. 14-9b and c right across the wall of the lecture room. Telescope parties are arranged, to look at Moon and planets. For this, small telescopes are more useful than a big observatory. An equatorial mount with worm drives operated by hand through flexible shafts is an enormous help to an instructor dealing with numbers of students. Small telescopes with inexpensive drives of this kind are now available.

DEMONSTRATION EXPTS. Week 6. Expts of Figs: 8-6a; 8-6b; 8-7; 8-10a(iii) // Expt of Fig 8-19b. Pendulum collisions, head on, elastic and inelastic. Glancing collisions of equal pendulums. Slide of alpha-ray tracks in helium. Expts of Figs: 5-3 (i), (ii), (iii); 5-7. Models of torsion, bending.

Week 7. Slides and posters of Figs: 12-1; 13-1,5,7,8,9,13,14,15,16. Large chart of Fig. 14-19b,c. Slides and posters of Figs: 14-1,2,3,4,5,6,7,8,11.

Week 8. Model of Fig 14-14. Large chart of Fig 14-19b,c for argument of Fig 14-15. Model of Fig 14-18. Earth-globe and arc to show equinoxes, etc. // Models and posters of Figs: 14-20,21,24,26. Poster of Fig 14-25. Set of transparent overlays to make Fig 14-27.

WEEK	MATERIAL FOR LECTURES AND CLASSES		ASSIGNMENT (Issued before week begins required by end of week)				LABORATORY
	CHAPTERS (pages)	TOPICS	READING Ch.	PROBLEMS Ch.	Problem Numbers	(pages)	
Week 9	16	Copernicus ------	16	16	1,2,3,5	(p.250)	Review of pend. graphs Demonstrations of SHM (see pp.172-175) Brief investigation of SHM of loaded spring
	17	Tycho Brahe	17	4	1+2+3+4 (L) before pressure lab.	(p.69)	
Week 10	18	Kepler ------	18	16	4	(p.250)	Pressure measurements ※ EXPT E(1) Ch.4 (p.71) (Supersprings continue)
	19	Galileo	19	17	1,3,4	(pp.259,260)	
				21	1(T)	(p.295)	
Week 11	21	motion in circle derivation of a = v^2/R demonstrations	21	18	1,2,3	(p.271)	Boyle's Law test EXPT E(2) (p.72) Preliminary discussion of apparatus of E(3) (Supersprings continue?)
	19		19	21	2,3 4	(pp.301,303) (p.310)	
	20	------ Galileo and astronomy	20	11	9,10,11,12,13	(p.203)	
		17th century; Descartes ※ (Newton) ※	22	22	1(P)	(p.312)	
Week 12	22	Newton: inverse sq. gravitation test on Moon Kepler's Laws I,III ------ Kepler's Law II planetary masses; comets Earth's bulge; "g"; tides rotational momentum		21	4,5a,5b	(p.310)	Boyle's Law ?※ EXPT E(3) (p.72) and drawing of graphs (Supersprings continue?)
				22	2	(p.334)	
				4	4,5,6, [8] (after pressure lab)	(pp.69-73)	
				1	16	(p.23)	

DEMONSTRATION EXPERIMENTS. Week 9. Poster of Fig 16-1B. Mechanical model to illustrate Fig 16-2 (gears and spoke carrying flashlight to make spot on ceiling to represent J*). Earth-globe to illustrate Fig 16-6
Models of Figs: 17-1; 17-2. Slides and posters of Figs: 17-2,3,4,5,6,7,8.

Week 10. Posters of Fig 18-1. Slides and posters of Figs: 18-4; 18-8; planetary data table (p. 268). Demonstration of regular-solids-argument, with cardboard faces and models.
Expts of Figs: 19-4; 19-2a (with long track and electric eye to measure speed at lowest point).
(Now or in Week 11) slides and posters of: Moon photos; Fig 19-7.

Week 11. CIRCULAR MOTION. Expts. of Figs: 21-4b (let go); 21-13 (very useful for discussion); 21-12c; 21-19 (and duplicate track with piece at top of loop removed); 21-24. Slide of 21-22. (In lab, expt of Figs 21-12 to 20)
ASTRONOMY (see also Week 10) poster of Fig. 20-21.

Week 12. Posters of Figs: 18-6; 18-7; 18-11a,b; and tables for Kepler's Law III (p.268). Expts of Fig 22-14. Poster of Fig 22-27.

WEEK	MATERIAL FOR LECTURES AND CLASSES		ASSIGNMENT (Issued before week begins required by end of week)				LABORATORY
	CHAPTERS (pages)	TOPICS	READING Ch.	PROBLEMS Ch.	Problem Numbers	(pages)	
Week 13	22 23 (24)	precession; gyroscopes Moon's motion perturbations ------ measurements of G ※ Neptune discussion of theory	23 (24)	22 23 25	3,4,5a,5c 1,4 1(T)	(p.335) (p.340) (pp.356-358)	Test of F = mv^2/R (Ch. 21, pp 308-310) (Also, optional test with conical pend.)
Week 14	25	kinetic theory: introduction demonstrations measurements of air-density and pressure: average speed ------ diffusion Zartman's expt effect of temperature	25	25	2(T) 3,4,5,6 7,8,9,10 11,12,13	(p.359) (pp.360,364) (pp.366,367) (p.369)	Heat transfer EXPT F(1),(2),(3)(4) (Ch.4 pp.73-75)
Week 15	6 9	surface tension ※ ------ Bernoulli; fluid flow ※	25 (6) (6) (9)	25 6 9	8,12,13 2,4 5,6,7 6,7,8 [2,3,17,18]	(pp.366,369) (pp.88,95) (pp.101-104) (pp.164,167) (pp.159,160,169)	Heat transfer EXPT F(6),(7)(8)(9) and demonstration of F(10). (pp. 75-77)

DEMONSTRATION EXPTS. Week 13. Cavendish Expt (rough measurement of G by estimating acceleration of system from rest.) Poster of Table of G measurements (p. 338). Expts of Figs 22-21; 22-20; 22-22. Slides and posters of Figs 22-30; 22-31

Week 14. KINETIC THEORY. Expts of Figs: 25-1; 25-9; 25-10; 25-13a,b; 27-9b (just to show effect of hot water). Model of Zartman's Expt (lead balls falling on to horizontal spinning bucket with slit in its side). Models of gas with steel balls, etc. Slides relating to uranium separation. Brownian motion of smoke on view in lab.

Week 15. SURFACE TENSION. Some of Expts of Figs 6-1; 6-2; 6-13,14,15,17 (Expt of Fig 6-19 postponed until after assignment problem); 6-23; (6-24); 6-25, 6-26. The only expt that is essential for later use is an oil molecule measurement, Fig 6-26 (expanded into problem 5) on a waxed tray filled to the brim with clean water and dusted with lycopodium, and an oil-drop measured against a 1/100 inch scale in a projection lantern.

FLUID FLOW. Expts of Figs 9-1,2,5,6,(13),15(c),19,24,25,29

SPECIMEN PROGRAM OF TOPICS AND ASSIGNMENTS FOR ACTUAL COURSE - SECOND SEMESTER

If the division between semesters is made at this point, Kinetic Theory of Gases has been started. That material needs to be reviewed and continued, in preparation for the following chapters. Chapter 25 Prob 1(T), the essential beginning of Kinetic Theory, was assigned in Week 12, before that topic was discussed. Prob 2(T) which puts the result in algebraic form, should be assigned again and regarded as part of the second semester's material both for use and for examinations. Re-assignment of Chapter 25's problems 3-10 depends on how they were treated in the first semester. Probs. 4 and 7 are essential for a working knowledge of molecular speeds; Probs. 3,5,6,8,9 encourage qualitative discussion which will be useful later; and Prob. 11 (uranium) prepares for Prob 3 in Ch. 30. Chapter 25's Probs. 13 and 14 are essential preparation for discussion in Ch 30.---if reassignment must be avoided, at least these two should be postponed until the second semester.

WEEK	MATERIAL FOR LECTURES AND CLASSES		ASSIGNMENT (Issued before week begins required by end of week)				LABORATORY
	CHAPTERS (pages)	TOPICS	READING Ch.	PROBLEMS Ch.	Problem Numbers	(pages)	
		ASSIGN					
Week 16	26 (370-380, 382-390)	energy: fuel, forms work machines kinetic energy expression mass and energy	25 26	25 26	2(T),3 4,5,6,7,8,9,10 1(T),2(T),4(T) 5,6,7,8,9,17	(pp.359,360) (pp.364-366) (pp.377,378) (pp.408,409)	Heat measurements Ch 27. (pp 413-415) EXPT A DEMONSTRATION EXPT B EXPTS C, (D), E Meas't of thermal conductivity of Al
					DUE		
		ASSIGN					
Week 17	26 (381, 390-407)	P.E.+K.E. conservation perpetual motion (power) Rumford et.al.	26 27 28	25 26 28 29	11,13,14 10,11,13 9 1,2	(p.369) (p.409) (p.430) (p.443)	Power measurements Ch.28 (pp 428-429) EXPTS A (i,ii,iv,v) B (i), D, E

※ MEANS "MATERIAL EASILY OMITTED IN SHORTENING THE COURSE"

DUE

DEMONSTRATION EXPTS. Week 16. [KINETIC THEORY --- if not shown before: Expts of Figs: 25-1; 25-9; 25-10; 25-13a,b; 27-9b (just to show effect of hot water). Model of Zartman's Expt (lead balls falling on horizontal spinning bucket with slit in its side. Models of gas with steel balls, etc. Chart of Fig 30-1a. Slides relating to uranium separation.] Brownian motion of smoke on view in lab.

ENERGY. Expts of Figs: 26-3,5,8,(9),12,14,15,17,19,23,25,29,30,31,42. Energy-interchanges shown by: pendulum; firework; loaded spring oscillates; battery first lights lamp, then electrolyzes water, then drives motor which raises load; falling load drives motor as generator. Student climbs rope, rewarded by measured sugar.

Week 17. Conservation illustrated: long pendulum; expts of Figs: 19-4; 19-2a (+ photocell + clock to measure v at lowest point); disc and axle on cords. Slides and posters of perpetual motion machines. // Student timed while climbing rope (HP). Hammering lead. Big wall-chart reproducing Fig 29-1+2 --- for discussion of early stages.

WEEK	MATERIAL FOR LECTURES AND CLASSES CHAPTERS (pages)	TOPICS	ASSIGNMENT (Issued before week begins required by end of week) READING Ch.	PROBLEMS Ch.	Problem Numbers	(pages)	LABORATORY
Week 18	29 30 (444-446)	Joule's work and results ------ idea of temperature ✳ gas temp. and mol. K.E. gas thcrmometer	29 30 (444-448) 32 (503-506 for L.)	26 30 ---- 32	15,16 1,2,4,5,6,7, (3) 11,12 - - - - - - - - 1 (TO PRECEDE 7,8 LAB WORK)	(p.409) (pp.444-448) (pp.459-460) (p.504) (p.510)	"Joule experiments" Ch.29 EXPT A (p.442) Water-churning meas't (continuous flow hydraulic brake)
		(If possible, introduce equipartition in lectures of Week 18; then let students learn by doing problems 1,2,3,4,5,6 of Ch. 30 . If not, postpone these problems in exchange for probs 19-22 of Ch.26.)					(NOTE Problems on Ch 32 must fit with lab program)
Week 19	30 (444-460)	equipartition + mol. mass M.F.P. and mol. size ✳ diffusion viscosity ✳ ------ diffusion pump ? ✳ M'Leod gauge ✳ vapor pressure ✳ saturated vapor ✳	30 32 (507-511 for L.)	26 30 28	19,20,21,22 3,8 , 9 13,14,15 11	(p.410) (pp.446,448,452) (pp.460,461,464) (p.430)	Electric circuits Ch.32 (pp.505-511) EXPTS A, B, C, (D) Communal expt: Fig 32-22 EXPT E: calibrating ammeter (communal) EXPT F if time permits
Week 20	30 (454, 461-464)	demonstration of viscosity ✳ discharge tube ? ✳ boiling ✳ triple point ✳ ------ critical temperature ? ✳ liquid air ? ✳	30 32	26 30 --- 32	23 17,20,21 - - - - - - - - 2,3,4,5,6 ALL 9,10 (L)	(p.411) (pp.464,465) (pp.508-511) (pp.513,515)	Voltmeters Ch.32 (pp.513-517) Expt F (i)(ii) if not done before Expt G and discussion of pressure meas't and potential diffce EXPT H: calibrating V.

DEMONSTRATION EXPTS. Week 18. Big-wall-chart reproducing Fig 29-1+2, for active discussion. Slides of Tables of results (see pp. 439-441). Bag of shot hauled to ceiling, dropped several times for rough meas't of J. Slide of Rowland's calorimeter. // Thermom'r of Fig 27-39 in ice and boiling water, and graph of Fig 27-11 drawn and discussed (later used for temp. of liquid air). Big chart of Fig 27-13. Equipartition illustrated by marbles agitated in glass tray.

Week 19. Charts of Figs: 30-1a; 30-3; 30-13 and ensuing reasoning (that chart kept up for weeks). (Expts of Figs: 25-13a,b if not shown before.) (Bromine, Fig 25-10, rough meas't of diffusion speed in air to estimate MFP). Wig-wag of Fig 30-16 (preliminary showing, 1 atm to 0.01 atm.) // App. of Figs: 30-19,20a,20b shown. Ether inserted in barometer to show v.p.

Week 20. Expt of Fig 30-16 pursued to high vacuum, meas'd with M'Leod, to estimate MFP. Expts of Figs: 30-31+32; 30-28 to illustrate ionization by collision. Water boiling at various pressures. Expt of Fig 30-25. Expt. of Fig 30-26 demonstrated in lab.// Expt of Fig 30-21. Liquid nitrogen and oxygen expts (p.462). After Prob 8 of Ch. 30 has been done, show model of Fig 30-5 (2 tennis balls on rod, with cross rods) and charts of Figs 30-6,7,8.

WEEK	MATERIAL FOR LECTURES AND CLASSES		ASSIGNMENT (Issued before week begins required by end of week)				LABORATORY
	CHAPTERS (pages)	TOPICS	READING Ch.	PROBLEMS Ch.	Problem Numbers	(pages)	
Week 21	33 (533-535)	electric charges ✻ electroscope + battery ✻ induction ✻ Coulomb's Law ------ fields, ice pail ✻ field strength inverse sq. test(Maxwell) ✻	33 32 511-517	33	2 5,6,7,8	(p.538) (pp.541-544)	Ohm's Law etc. Ch 32 (pp519-521) EXPT I (constantan) EXPTS J, K (lamps) EXPTS Q,R (p.523) Optional,for fastest students: K,L,P,S
				32	20 (L) 12,13,14,15,16 (L) (use "rigmaroles")	(p.529) (pp.517-518)	
Week 22	33 (552, 555-562) 35 (600-603)	Coulomb constant ✻ electron stream and electric fields cathode rays ------ electrolysis e/M for ions	36 32 (518-520)	33	10 14,15,16	(p.553) (p.566)	Diode Tube Ch. 32 (pp 520-522) EXPT M(0) (= try pot'l divider: Fig 32-34) EXPTS M(1),(2),(3) and plot graphs EXPT M(4), if time
				36	1(P),2(P),3 7,8	(pp.606,607) (p.612)	
				32	18,19 (L) 22,23,28,29,31 (L)	(pp.521,526) (pp.529,530)	
Week 23	36	electron streams ions in air Millikan	36	36	4,5,6 (7,8, if not done already)	(pp.608-609)	A.C. Experiments etc. Ch. 32 (pp. 522-526) EXPT M(4) (Diode) EXPTS T,U,V (A.C.) EXPT W (DC power line)
				32	27,32,33(all L) 30(T)	(pp.529-530) (p.531)	
Week 24	34	magnets and fields ✻ current fields magnetism: theory (✻)	34	34	3,4,5	(pp.574,581)	Magnetic fields ✻ Ch. 34 (pp 570-571) EXPT F Also sketch catapult field (Fig 34-16)
				36	11	(p.614)	
				32	34 (L)	(p.532)	
				33	11(L)	(p.558)	

DEMONSTRATION EXPERIMENTS. Week 21. Show quickly some of following: Expts of Figs: 33-3,6,7,8,9,10,11,12,13a,13b,15,21,32 Coulomb's Law (Fig 33-17, or use film of this).

Week 22. Measure Coulomb's-Law-const.(Fig 33-37). Oscilloscope in use. Expts of Figs: 36-2; 37-4, preliminary showing; 37-5. Cathode rays cast shadow. // Electrolysis: lead tree, water, copper sulphate, molten glass. Chart of periodic table. Chart of e/M measurements for ions (kept on display from now)

Week 23. (Current from Van de Graaff through microammeter. Current carried by flame). Electroscope with flame, α-, β-rays, ? X-rays. Large model of Millikan expt with charged balloon. Exhibit of clouds of fine particles falling in liquid (terminal velocity).

Week 24. Show quickly some of following: Expts of Figs: 34-1, 2a, 5. Field patterns of magnets and of currents, Figs: 34-11, 12,16. Expts of: Figs: 34-17+18 (in latern); 34-22 (model with many small compass needles, another model with pivoted coils carrying current); 34-26; 34-31 (? postpone till after Ch 37).

	CHAPTERS (pages)	TOPICS	READING	PROBLEMS			
			Ch.	Ch.	Problem Numbers	(Pages)	
Week 25	37	catapult forces force constant B' ※ ------ catapult forces on moving charges e/m for ions + electrons	37	37 39	1,2 3 1(P),2(P) 3(P),4(P)	(p.616) (p.621) (pp.631,632) (p.632)	"Magnets and Coils" Ch.41 (pp 655-662) EXPTS A,C(1)-(8), E (AC power line) [D,G(1),G(2)]
Week 26	36 (610-611) 37 38 39	(discharge tube) e/m; e/M mass spectrograph ※ ------ radioactivity: ions, electroscopes, radiations counters	30 (462-464) 38 39 (633-640)	37 38 39	(3),4,5,6 1,2,3,4 5(P)	(pp.621,622) (pp.625-628) (p.632)	Triode Amplifying Ch. 41 (pp 662-664) EXPT H (1),(2),(3),[(4)] Demonstration radio set
Week 27	39	cloud chamber alpha,beta,gamma rays ------ radioactive changes half life	39	38 39 42	5 7,8,12,13,14 1(P),2(P)	(p.629) (pp.645-647) (p.671)	Electrons: e/m speed Ch.41 (pp 667-668) EXPT I (Leybold App.) Demonstrations:counters, cloud-chamber
Week 28	40 43 (682-688)	atomic models alpha ray scattering Rutherford atom nuclear equations nuclear energy (lithium example)	42 40 43 (682-688)	39 40 42	15 1,2 4	(p.648) (p.653) (p.681)	Visit to Cyclotron Radioactive Decay Expt Lauritsen electroscope, or counter, (p.644), with N-13 from proton bombardment of mylar. Demonstrations of: cloud-chamber; α-counter; β-counter with magnet. Visits to Research
Week 29	43	positrons neutron discovery neutron bombardment nuclear structure fission ------ reactors mass per nucleon nuclear energy	43	39	9 16,17,18	(p.646) (p.648)	
Week 30	44 (parts)	photoelectric effect interference of light photons pair creation ※ ------ electron waves; matter waves (Bohr atom) ※ uncertainty; complementarity	43 44 (parts)	43 44	3 2+3	(p.693) (p.726)	Visits to Research ※ or Oscilloscope Expt ※ Ch. 41 (pp 668-671) EXPT J(1),(2)

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NOTES OF DEMONSTRATION EXPERIMENTS , WEEKS 25-30

DEMONSTRATION EXPERIMENTS. Week 25. Expts of Figs: 37-1,3,4,8,9,10,15b(i). // Measurement of e/m (Fig 37-6).

Week 26. Discharge tube. Tube showing positive rays. Model mass-spectrograph. (When available, helium leak-tester). Expts of Figs: 39-4; 39-13a,b; 39-14, and then open-air spark-counter for alpha rays. Beta ray counter (with decade scaler led out to large dials of neon lamps.) Expts of Figs: 39-5+6, with counters.

Week 27. Counters. Projection cloud-chamber. Slides of cloud-chamber photos (most of the photos in the text, with large captions added. These photos are then exhibited as large transparencies in corridor) // . Analogue of radioactive family, (cascade of jars of water with capillary spouts). Beta ray counter to show decay (e.g., of silver after slow neutron bombardment). Chart of periodic table (kept on display from now).

Week 28. Cloud-ch. photos of α-rays. Models of alpha scattering: (i) steel balls (after running down incline) meet shallow humps (Thomson atoms), or a forest of thin posts (Rutherford atom) --- seen by shadow on ceiling; (ii) electrostatic model with light charged ball on long thread repelled by Van de Graaff. Large chart of table of alpha particle scattering (p. 652). // Large chart: calculation of 931 Mev per a.m.u. (kept on display) Large chart of Fig 43-34. Chart of stable and unstable isotopes (kept on display)
Large crude models (2 ft spheres or cubical cartons) to represent nuclei: show β-and γ-emission by concealed spring and flash-bulb; ball rolled up sloping plank for α-scattering; horizontal plank for neutron bombardment: if bombarding particle falls in, concealed spring ejects new particle; U-235 nucleus, with energy stored in big springs, is tripped to fission by a neutron hitting a spring trigger inside model, and releases spare neutrons.
Tomato plant given radioactive phosphorous, tested with β-counter at beginning and end of hour (? postpone to later lecture).

Week 29. Cloud-ch photos. Beta ray counter with β^- source, then with positron source, with lead screens and horseshow magnet arranged to discriminate between β^- and β^+ (arrangement magnified by shadow). Hugh photo poster of Chadwick's letter to Nature, suggesting neutron. (If not done earlier: neutron bombardment of silver with water moderator, (Fig 43-22c), and β-counter). Boron neutron counter with pre-amp., discriminator, scaler, loud speaker; with paraffin-wax moderator, then with water moderator; with screens of lead, cadmium, inserted before and after moderator. Chain reaction with book of matches. (Mousetrap model). Slides of methods of separating U-235, Slides of Figs: 43-27; 43-32a. Large chart of Fig 43-34. (Tomato plant given radioactive phosphorous, tested with β-counter at beginning and end of hour.)

Week 30. Expts of Fig 44-8a. X-ray tube and gamma counter, with X-ray screen reduced to show quanta one by one. (Films of photon demonstration experiments). Photons from lighted match shown by alpha counter. Large photo-poster of de Broglie's letter to Nature suggesting matter waves. Ripple tank to show Figs: 10-23; 10-22 and 44-30. Cloud chamber photo. Model shown in Fig 33-31.